# METAL PROGRESS

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The remarkable Kodachrome of the big forging hammer,
with an open heating furnace seen between the hammer up-
rights and dies, is used on this month's cover through
the courtesy of Ladish Drop Forge Co. of Cudahy, Wis.

# THE PRESENT STATUS

# OF ELECTROPOLISHING

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ELECTROPOLISHING is an established commercial process, and is solving a variety of production problems. It is not a cure-all, as some of its proponents have claimed, but neither is it a mere laboratory curiosity. Its growth as a production tool has taken place during the last six years while its patent status has been in controversy. This legal situation has now been clarified.

There are, of course, several different electropolishing processes* which include such solutions as mixtures of perchloric and acetic acids; of sulphuric and citric acids; of phosphoric acids and certain alcohols; of phosphoric acid and glycerine; of sulphuric and hydrofluoric acids; and of sulphuric and phosphoric acids. So far as is known, the latter solutions, developed by Pray and Faust and their associates and covered by patents owned by Battelle Development Corp., have received more extensive commercial investigation than any others and the remarks herein are therefore confined to experience with them.

**Outline of the Process** — The product to be polished is racked individually and made the anode in a bath of proper composition, and direct current is applied in such a way as to "de-plate" the article. This removes the surface layers of metal more rapidly from the tiny protruberances on any surface and thus tends to exert a smoothing action on the surface of the metal. It will

*Electrolytic polishing of metallographic samples was described as long ago as 1935; Messrs. Pellissier, Markus and Mehl summarized the published data on solutions and technique in a *Metal Progress* Data Sheet, published in January 1940 and republished frequently since.

produce a surface ranging from bright luster to mirror-like, depending upon the original condition and the treatment given the metal part.

Following this "polishing" operation, the product need only be washed and dried.

The operating conditions used in the process are generally comparable to those employed in chromium plating, they are non-critical, and these conditions and the baths themselves are controlled simply. Current densities may range from 100 to 500 amp./sq.ft., with 200 to 250 as a general average. Temperatures may vary from 115 to 250° F. with most operations conducted between 125 and 140° F. The voltages are between 2 and 18, with most applications using 6 to 8 volts. Time of treatment may be from 1 to 40 min., with the majority of products requiring only 10 to 20.

The baths have better than average "throwing power", compared to common electroplating solutions, and special conforming cathodes are required for none but a relatively few complex shapes. Bath maintenance and control have been simplified to the point where specific gravity measurement is usually sufficient. Very little fuming occurs during operations and the industrial hazard is less than with chromium plating.

The equipment consists of lead-lined steel tanks. Racks have excellent life because they can be readily protected with standard stop-off treatments.

The Battelle process was originally developed as a means of producing a bright decorative

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surface on the chromium-nickel stainless steels. Through continuous research, it is now applicable to both the chromium-nickel and the straight chromium stainless steels and to carbon and alloy steels, aluminum, zinc, copper, nickel, and many of their alloys.

In addition to providing a bright decorative surface on these metals, it has been shown that the process may be used for de-burring, for removing scale, for polishing intricate shapes which cannot be reached with mechanical equipment, for preparing base metals prior to plating or enameling in order to secure improved adherence, for smoothing parts to reduce skin friction, and for reducing slightly oversized parts to precise weight by uniform removal of metal from the entire surface. New applications are being discovered and this list may well be expanded in another year.

In determining the value of the process for these purposes, a variety of products from a number of different companies have been studied. These have included automobile bumpers, hub caps, radiator caps, horn buttons, windshield wipers, insignia, gears, hardware and dash panels; watch springs, pivots, cases, and gears; refrigerator hardware, trays, and shelves; surgical and dental instruments; aircraft and automobile engine spark plugs, piston rings, and valves; cutlery, tableware, vacuum bottles, electric irons, waffle irons, toasters, and various kitchen utensils; saws, files, drills, reamers, bits, wrenches, pliers, cutters, and similar tools; a variety of aircraft parts; metal milk containers; tubing; wire; needles; household and cabinet hardware; costume jewelry, watch bracelets, belt buckles, and luggage hardware; telephone parts; dies and molds; pipe fittings, bathroom hardware, and plumbing fixtures; instrument and meter parts; screws; printing and engraving plates; musical instruments; chemical apparatus and machinery; metal office and home furniture.

## Some Findings and Limitations

As a result of this work on the process, one fact is outstanding, and that is that few generalizations can be stated. Each application requires individual study and each installation must be custom-built. The variations between products — and even between the practices of different manufacturers of the same product — make this conclusion inevitable. Conditions which make the process technically and economically desirable in one plant make it entirely unacceptable in others. A few typical cases will illustrate the difficulty in generalizing:

Stainless steel castings obviously have ro
uneven surfaces. As cast, they have a dull,
tractive appearance. They cannot be bright
by any mechanical means which will reach
into the pits and brighten the entire sur
Mechanical polishing to secure a smooth, b
surface is too costly for most applications.
ever, such castings can be brightened readi
electropolishing because the solution gets
the base of the pits, cleans them out and prod
a bright surface. As a result, electropoli
stainless steel castings have an unusual lu
even in the rough state, which makes them
attractive than unpolished castings and
enhances their sales value.

However, this ability to brighten the bot
of deep pits, scratches and tool marks someti
reacts against the process. For example, m
die marks and even correct depressions
emphasized. Certain watch cases could not
electropolished because of the die marks sta
ing the manufacturer's name, nor could
which showed severe die marks. When eithe
these was first mechanically polished to smoot
the irregularity, an improved finish resulted w
electropolishing was employed as a final
However, neither product could stand the exp
of the dual treatment.

It is this tendency of electropolishing
attack the base of pits, cuts, and such depressi
which makes the process more suitable a
finishing, rather than as a roughing operati
Yet there are two definite exceptions to this
eral statement:

Stainless steel sheets, as well as certain
bon steels, contain impurities which show up
slag stringers or pits. When such a plane surf
is *mechanically* polished, the metal is pee
down or flowed over these defects and effectiv
conceals them. When this surface is then e
tropolished, the thin surface layers are remo
and the defects re-emerge. This condition d
not exist in steel free from these defects,
such steel is not always procurable — or
desirable. Such was the case with an engra
of stock certificates, bank notes, and bonds
sought to eliminate hand burnishing of his pl
by electropolishing, but refused to change
grade of steel to make that possible. Yet
proof of this possibility is found in the exp
ence of two molders of plastics who elimina
the fine grinding marks on their dies by giv
them a final electropolish.

The second exception to the rule that elec
polishing is primarily a finishing operation
illustrated in the manufacture of watch brace
and certain kitchen utensils. The standard p

with the watch bracelets was to tumble them, then clean, then wheel polish, and finally wheel buff them. Electropolishing eliminated tumbling, cleaning, and wheel polishing, but a wheel buff after the electropolish improved the "color". The costly operations, however, had been removed by electropolishing and the dual process is economically attractive.

The kitchen utensil mentioned has a semi-spherical shape and is of a size which makes

wheel polishing and buffing impractical on the interior. Hence, a hand machine was used for this job and results were not too satisfactory. It was found that an almost mirror-like surface could be produced on both the exterior and the interior by electropolishing, but the amount of metal which had to be removed was excessive. By trial and error, it was found that electropolishing could be used as an initial operation to bring the surfaces to a bright finish, but mechanical buffing would be employed as the final step. This combination of electropolishing and mechanical polishing produced an improved finish and cut out about 80% of the mechanical polishing previously required.

These illustrations have been cited to show why individual studies are necessary in each potential application. They also show some of the limitations of the process and they demonstrate that in some instances combinations of electropolishing and mechanical polishing may be better than either alone. It can also be stated that the process is not now commercially applicable to heavily leaded brass, to cast iron, or to zinc or aluminum die castings; certain steel alloys also give trouble.

**A Utilitarian Application** — Most of the applications of electropolishing are to better the surface, either to the edge, or to smooth it for some technical purpose. An incidental application is as a metallurgical inspection tool on austenitic stainless steels. Certain heat treatments, intentional or accidental, put them in a structural condition in which they are susceptible to certain chemical corrodents. If such metal is subjected to a controlled electropolishing operation which gives a mirror surface on stabilized stainless (whose corrosion resisting properties have not been impaired) a visibly pebbled surface will result. By electropolishing a small spot on a suspected piece of stainless, the absence or presence of the undesired condition is readily revealed. A portable gadget allows a workman to do this "spot-testing" quickly and conveniently in the final inspection before shipment.

## Advantages of the Process

The advantages of the process are numerous and can be described with typical cases.

**Decorative Finishing:** The rating of decorative finishes is not subject to quantitative evaluation, but is purely a matter of personal opinion with decisions in the hands of people who must pass upon sales value. Such authorities have given their unqualified approval to electropolished finishes on nickel plated irons, toasters, percolators, and domestic equipment, and on costume jewelry. These are products on which final finish is of utmost importance, because they are viewed at close range where minor defects become promi-

nent. Electropolished finishes have a superior rating because of the "color" resulting from a complete absence of wheel marks.

Such superior results may frequently be achieved by plating nickel directly on unpolished steel and confining the electropolishing entirely to the nickel overlay — economical production, in addition to improved appearance.

Recently an entirely new finish has aroused considerable interest. By means of an abrasive action like shot blasting, a pebbly finish is given the surface. This is then electropolished to a bright luster, resulting in a finish varying between the "butler" finish found on silverware and a bright, sparkle finish. It has the distinct advantage of hiding finger marks and scratches, and requiring much less frequent polishing in the home. It is by far the cheapest finish which can be applied because no preliminary wheel work need be done.

A two-tone effect with various designs can be given by protecting certain areas during the abrasive operation and then electropolishing the entire piece. The abrasive-treated areas will have the non-reflective matte finish, while the plane areas can be polished to a mirror-like surface.

**De-burring:** When electropolishing is used solely as a de-burring operation, it has no particular technical advantages. It can then be used only where it is cheaper. When the de-burring operation can be combined with the finishing operation, the advantages are obvious. This can be done on certain aircraft parts, gears, tools, and fittings. Experimental work indicates that it may also be applicable to stamped products such as spoons, forks, knives, and other ware.

In practically all cases, the success of a de-burring operation is dependent upon the size of the burrs. Small burrs can be removed readily, and smooth, rounded edges are produced.

The throwing power of the solution is such that the interior threads of female fittings can be cleaned with out the use of special conforming cathodes.

Where large burrs exist, how ever, their removal involves an ex sive loss of metal from the other areas. This sometimes reduces the dimensions below permissible to ances; in other cases, it is too c in chemicals for the baths. T objections can be overcome by use of stop-offs on the smooth are but this, of course, adds anot manual operation.

**De-scaling:** With most produ de-scaling can be done more chea by other methods. There are so instances, however, where elec polishing has a place. For exam certain silicon steel parts wh require a smooth, bright finish h been de-scaled and brightened i two-step electropolishing proce with two solutions. In anoth instance a single bath was entir adequate to remove a heavy sc from some stainless steel aircr parts.

Its most economic utilizati occurs when de-scaling is combin



*Another Example of Uniformity*
*Electropolish on an Irregular Surfa*
*— a Formed Strip Placed Vertically*
*Left of a Cupola-Charge Schedu*

with bright finishing as a single treatment. Th is some evidence that de-burring may also included in this single step. However such a co bination of treatments is able to remove no m than a relatively light scale.

**Electropolishing of Complex Shapes:** Elect polishing is without competition in its ability polish complex shapes, the surfaces of which almost inaccessible to a wheel. Such products gears, welded aircraft hoods, band instrumen costume jewelry, canteens, milk cans, therm bottles, drills, tubing, can be polished in th innermost recesses with as satisfactory a fini as can be produced on any readily accessible are The depressions and cavities of a normal rel design, stamped or rolled, such as designs tableware, watch bracelets, jewelry, decorat

molding and flashing, are emphasized to a degree difficult to duplicate otherwise.

Special cathodes depend upon the shape of the product and dimensional tolerances. The throwing power of the solutions is sufficient to reach some cavities with flat cathodes; specially formed cathodes are readily made from lead and may be used over and over again.

**Improved Adherence of Plate and Enamel:** Electroplated and enameled finishes must have adequate adherence to the basis metal. In the past, basis metals have generally been prepared for plating or enameling by mechanical polishing. Subsequent failures of the finish have frequently been charged to an inferior bond between the basis metal and the plate or enamel.

While this assumption may frequently have and exposes the true metal itself. When a plated or an enameled finish is deposited on this surface, no weakened surface layers exist within the base and, consequently, failures are less likely.

This value of electropolishing has been demonstrated in such applications as chromium plated piston rings, dies, bits, drills and similar tools, as well as enameled kitchen utensils. Further applications are being considered.

**Machining:** Electropolishing may attain some value as a machine tool! In one instance, a very small, but critical part in a military device had to be produced to exact dimensions with very close weight tolerances. It was shown that excellent results could be secured with electropolishing because metal was removed uniformly by closely controlling the time.



*Electropolished Sheet, Stood on Edge Behind Copies of Your Favorite Technical Magazine, Reflect the Cover Designs Almost Like a Mirror*

been correct, there is ample reason to believe that it has not been correct in all cases. Recent work by several investigators has shown that the hardened surface, due to mechanical working, weakens the bond between these hardened layers and the underlying normal basis metal itself. Subsequent stresses on the plate or the enamel further weaken this bond and failure results. In such cases, this failure occurs in the bond between the basis metal and its weakened surface layers and not in the bond between the surface layers and the plate or the enamel.

Electropolishing of the basis metal prior to plating or enameling removes all surface layers

In another case, certain steel and brass screws had to be made to tolerances beyond those of a screw machine. Here again it was demonstrated that electropolishing could produce the desired results.

In another rather large part used on aircraft, control of weight was an essential factor. Electropolishing proved to be an excellent means of achieving the desired result.

Other "machining" applications of electropolishing are now being studied. One such application relates to improving the micro-inch finish on smooth surfaces. Promising results have been obtained along these lines on some stainless

steels, on high carbon steels, and on the carburized surfaces of low carbon steels. Mechanically buffed surfaces having a 50 to 60 micro-inch finish have been brought down to 40 to 50 micro-inches, while surfaces with a 5 to 7 micro-inch finish have been improved to 3 to 4 micro-inches. In steels where the electropolishing exposes inherent pits and inclusions, the micro-inch finish has not been improved.

This tendency to improve smoothness is being explored in an effort to reduce the skin friction on parts through which large volumes of gases move at high velocities. No specific conclusions can be drawn from the work to date, but preliminary results are promising.

A third study under investigation relates to the shaping of gears by means of electropolishing. Inasmuch as the process can remove metal at rates between 0.0001 and 0.0005 in. per min., it is obviously rapid enough. The question is whether or not metal can be removed under control so as to maintain the required pitch. This application, of course, will necessitate specially designed electrodes. If successful it will materially aid production as it will shape and finish the product in a single operation, leaving the surface with a fine micro-inch finish, free from burrs and other defects which cause stress concentrations.

## Economics

However interesting electropolishing may be to the technical man, its true value is dependent upon its cost.

From the variety of applications recited, it is evident that no generalities can be drawn. The direct elements of cost include the chemical solutions, power, fixed charges on the equipment, and labor.

In the Battelle process, four different basic solutions are employed, the choice being based upon the metal to be polished. All of these solutions are comparatively inexpensive as their primary components are sulphuric, phosphoric, and chromic acids.

Life of such a solution is, of course, one element of cost to be considered. Some of the Battelle baths have finite lives dependent upon saturating the bath with metal, and this, in turn, is fixed by the amount of metal removed from the products treated. The other baths have practically infinite lives; losses depend upon drag-out balanced by make-up. The baths used for polishing copper and nickel precipitate these metals in a usable form, thus creating a credit. Because of these variables, no generalizations on solution cost are warranted.

This is equally true of power costs. Cur[rent] densities and voltages vary, as does time of b[ath] ment, and these, of course, determine power [con]sumption.

In the vast majority of cases studied, [solution] and power costs have been negligible parts o[f] total polishing expense. The major item of [cost] has been labor, and this has varied w[idely] depending on the product being polished. [Each] piece requires a firm electrical contact, and [this] necessitates individual racking. Where the sh[ape] permit the use of a simple rack, this work ca[n be] handled by inexpensive help; where large, c[om]plex shapes are polished a responsible, sk[illed] operator is required.

Equipment costs will vary depending o[n the] size of the pieces treated, the time required [for] treatment, and the number of pieces to be tre[ated] per day. Complete installations for handli[ng a] large number of small parts can be made f[or as] little as $4000. From this, first cost may r[ise] up to several times as much where comp[lex] automatic equipment is used.

Costs per square foot of area polished h[ave] varied between 2¢ and 90¢, and have proved t[o be] profitable in both cases.

The most advantageous overall costs [are] secured when electropolishing can be used [to] replace several operations such as de-scali[ng,] de-burring, tumbling, and wheel polishi[ng.] Electropolishing costs per unit may even the[n be] high, but the over-all savings make the pro[cess] unusually attractive.

It therefore results that only a comp[lete] analysis of each potential application can re[veal] the true value of the process.

## The Future

Obviously, no one is competent to fore[cast] the ultimate future. Sufficient experience has [not] been gained to reveal all of its advantages or [all] of its applications as a commercial process.

It has demonstrated that it has econom[ic] value and that it can compete successfully w[ith] other finishing methods under certain conditi[ons.]

Moreover, it is a new process. Continu[ous] research is being conducted to expand its use [to] additional metals and alloys. Its technical [and] economic limitations are being subjected to c[on]stant study in order that its horizon can [be] extended and that it can become a more use[ful] tool of the production man.

At this time when the reconversion to civil[ian] production is not too far away, it is certai[nly] advisable to explore its worth for all finish[ing] problems.

# FATIGUE TESTS AT
# RESONANT SPEED

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OUR ATTENTION was drawn to the possibilities of resonant systems for setting up rapidly alternating stresses when called upon to test a new type of coupling. The object was to determine whether or not they would loosen under repeated reversals of a minor load. The couplings were small and the force (200 lb.) to be applied was also small, but we had no equipment available that could do the job. So the first thing to do was to devise a piece of test equipment — something of an old story in an aircraft engineering laboratory.

Among the methods considered was the use of weights and a cam-operated beam, or an adaptation of the more-or-less standard type of motor-driven endurance testing machines. It has been customary to perform many tests of this nature by using a mechanical system, excited by a rotating unbalance driven by a constant speed motor. With this system it is impossible to continuously control the load applied to a specimen under operating conditions. The load not only cannot be varied at the will of the operator, but it is extremely sensitive to small changes in the mechanical system when that system is speeded up, especially when operating near a mechanical resonance.

Study of our problem indicated that a cam-operated beam, which could be simply constructed, should not run much faster than one cycle per second, and the test run specified as 84,000 cycles would have required 140 hr. of running time for the six specimens to be tested. Since such equipment is of such a nature as to

require constant attention and since our laboratory is a one-shift operation, we would not have an answer before 2½ weeks after the equipment was built. While that may not seem an exhorbitant time to research men who operate rotating beam fatigue machines for months, even years, our design engineers wanted an answer much sooner, if at all possible. The possibility, of course, rested in speeding up the test, and that brought us immediately to consider — and construct — a resonant system.

Essentially, the resonant repeated-loading unit we developed and shown in Fig. 1 consists of two massive fly-wheels connected by a "coupling spring". The specimen is mounted at the middle of the "spring", and forms a part of it. A resonant mechanical system is used. Its advantage is in the fact that the rate of application of the load is known and is the same for every cycle. Such a mechanical system, used in conjunction with the electronically controlled vibration motor (Fig. 2), becomes a precise and flexible tool for both structural tests and for the determination of certain properties of materials. It can be adjusted for any one of a large number of loading cycles per unit time, and its uniform loading is entirely independent of minor changes in the mechanical system.

It will be observed that the masses are slung from a supporting frame in such a way that they may swing like a pendulum, toward and away from each other. Now when the system is considered as a free body, the connecting spring is placed in tension when the masses are moved

apart, and the tensile forces are uniform throughout the spring length. The spring may be cut at any point and a sample inserted. Actually, the test specimen is made a part of the spring, or "compliance", of the system. Then, if a small oscillatory driving force is applied at the resonant frequency of the spring-mass system, and sufficient energy supplied to provide the energy loss due to damping in the system, the spring-mass system can develop forces of tension and compression in the sample of the order of 100 or more times the applied driving force. The peak force at resonance is directly proportional to the magnitude of the driving force and is controlled by adjusting the amplifier output.

Mass and spring values can be adjusted to

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*Fig. 1 — General View of Lockheed Fatigue Testing Machine Showing the Two Cylindrical Masses (and Power Unit at Far End) Slung From Overhead Supports, Cylindrical "Spring" Consisting of Concentric Tubes at the Axis, and Test Piece Held in Chucks Attached to "Spring"*
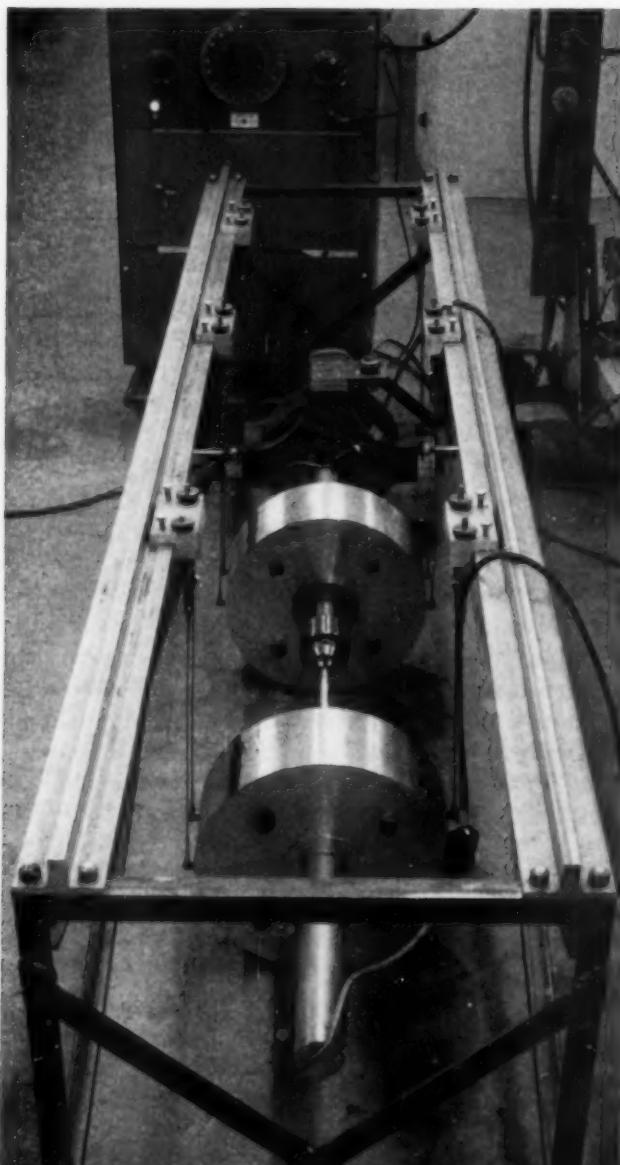


give the desired resonant frequency ranges. is accomplished by using concentric tubes lo axially as springs, and by using masses buil of steel disks.

In order to obtain sufficient spring ac (compliance) in a small space, the outer t (18 in. long projecting through the center of disks) are connected to the inner face of respective masses, and each is terminated at outer end in a plug. The longer inner tube fixed to this plug and extends beyond the and ends in a ¾-in. Jacobs chuck for grasp the test sample. As shown in Fig. 3, this prov easy attachment to a wide variety of round s ples. (Correction for the mass of the chuck unnecessary when testing stiff samples; howe the inertia forces due to the motion of the ch would have to be subtracted from the measu load force to give true loadings of compli samples.)

Driving force is supplied by an electrom netic vibration motor (Fig. 2) driven from oscillator and power amplifier. The magnit of the driving force is readily controlled by gain adjustment of the power amplifier. system can be "self-excited", and the amplit control can be made automatic.

At the frequencies used, the momentary the maximum tensile (or compressive) force the same at any position throughout the len of the tubes. The magnitude of the force app to the test specimen is therefore readily me ured by strain gages placed on the surface of tube. In our present unit, the gages are pl on the outer surface of the inner tubes for tection and electrical shielding; they are of whose calibrated resistance varies with its sion (see "New Pathways in Engineering" Alfred V. de Forest, Metal Progress, May page 719). The gage circuit is connected to amplifier and voltmeter to provide an indica of the load. Each mass and spring unit is ically calibrated and a conversion factor ma adjusted so that, for a particular sample, a scale voltmeter reading on the strain gage cir indicates the desired peak loading of stress in sample under test.

An outstanding factor of this method testing is that upon incipient failure of a sam the "spring constant of the specimen" (its s ness) changes and throws the system off r nance by reducing the resonant freque Therefore, an appreciable and continuing re tion in resonant frequency or load on the sp men, as indicated by suitable instruments, warning of impending failure or destruction the sample. This is a matter of great importa

neer more accurate data than have been available in the past. No small advantage is the fact that none of the forces involved are taken out in an external structure. Loads of 50,000 lb. or more may be applied without the noise and vibration which would accompany such mechanical testing. Because the equipment can be made self-attending it is possible for one operator to control several machines. Furthermore, the vibration motors, associated equipment, and the technique are readily adaptable to standard test pieces.

The resonant repeated-load unit has proven so successful in its initial service that we are building larger components of the same type, and of a torsional unit of similar nature.

*EDITOR'S NOTE — Investigators at Westinghouse Research Laboratories in East Pittsburgh have utilized the principles described by Mr. Rawlins for testing turbine blade material at high temperature. Owing to the rapidity with which impulses are received during the operation of a steam or gas turbine, turbine blades and stator vanes must have a useful life of several hundred million or even several billion cycles. By ordinary means it takes years to stress a sample a quarter of a billion times. The Westinghouse machine operates on a system resonating at 120 cycles per sec., and is powered by two stator coils connected to a two-phase 60-cycle line. A carefully designed furnace, compensating for heat lost through the specimen clamps, completely encloses the sample, and maintains it steadily at the desired temperature. Being hidden from observation, the fact that the specimen itself can register its first sign of failure is of utmost importance. Tests at 1500° F., run a billion cycles, are completely automatic and take about 100 days. ☻

for we want to see the specimen after the first tiny crack appears, not after its complete failure. The present equipment is useful over a wide frequency range. At 100 cycles per sec. a total of a million cycles is clocked up in slightly under 3 hr. Each cycle consists of a compression and tension loading.*

Probably the greatest single advantage is that the system is operated at the exact frequency at which the mechanical system happens to resonate, whereas in the past it has been necessary to carefully and laboriously tune the mechanical system to the resonant frequency desired. In addition, the applied force is under constant and complete control; in former equipment control of the force has often been inconvenient.

This technique saves both operating and set-up time in addition to providing the engi-



Fig. 3 — Bird's-Eye View of Cylindrical Test Specimen, an Integral Part of the Inner Tube Portion of the "Coupling Spring" by Jacobs Chucks
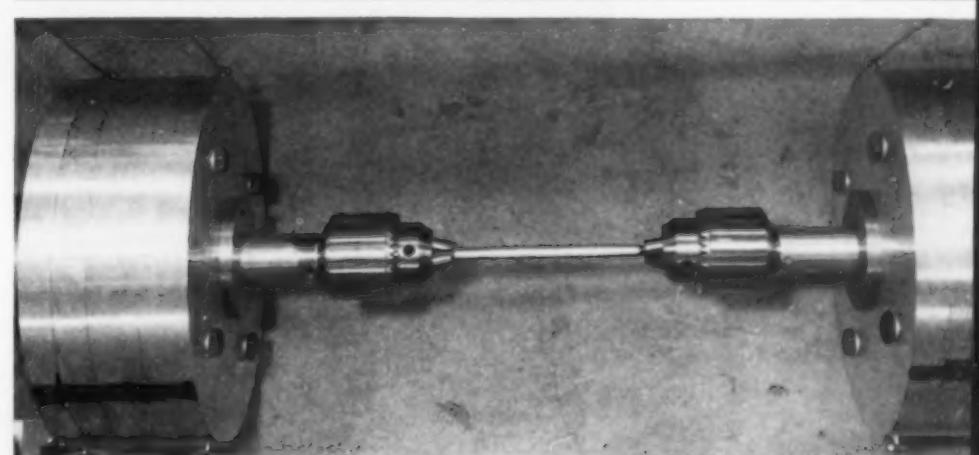
*Kent Robertson Van Horn*

PRESIDENT,

AMERICAN    SOCIETY    FOR    METALS

Every now and then, some person who thinks he indulges in original thinking repeats the observation that people often grow into a mold that is patterned by the nature of their work. Thus, after a certain formative period, such specialists as butlers, biographers, ball-players, bartenders, and metallurgists tend to conform, outwardly and inwardly, to the narrowing influences of their respective professions. Take metallurgy, for example: All ASMembers know how metallurgy affects a man. He becomes parochial, single-minded, and as uncompromising as the metals he pushes around. Moreover, he comes in time to *look* like a metallurgist — a subtle mutation the uninitiated cannot sense, for the profession is too young to have developed a distinctive physiognomy.

However, like all generalities, the foregoing is fraught with exceptions.

High up on any list of these exceptions comes the strange case of Dr. Kent Robertson Van Horn, assistant manager of the Cleveland Research Division, Aluminum Co. of America, and currently president of the American Society for Metals, who, though indubitably a metallurgist, has yet to take his final metallic vows and retire into his aluminum tower. For in addition to being learned in metals, the doctor is a Man of Parts, as his superiors in the Aluminum company — who thought at first that they had merely hired a research metallurgist — have come to find out.

There are several things about Van Horn that strike you. One is a keen aggressiveness that might be irksome in another, but in Van Horn manifests itself effortlessly and is combined with a disarming friendly nature. The effect is refreshing. Another is his organizing ability. He is not only well-organized himself, but also has the knack of tactfully and effectively organizing others, when the occasion demands. Finally, you cannot help but be impressed by his complete identification with the city of Cleveland, where he was born and where he would hate to leave.

Certainly, it is commonplace today for people to forsake their roots and spend their lives in a series of temporary stands, and this is especially true of engineers, the nomads of the Machine Age.

Within the confines of the Cleveland city limits, however, Van Horn is what a magazine writer would call peripatetic, for he is constantly on the move, like an energized atom, from one civic activity to another, and has acquired a first-name acquaintanceship with people in most of the strata of Cleveland's polyglot population, including the ballplayers of the Cleveland Indians and the musicians in the string section of the Cleveland Symphony.

His gregariousness and his organizing talents have more than once come in handy at the spreading Cleveland plant of Alcoa. There is the case of the Foremen's Club, a social organization which was organized in the interests of *esprit de corps*. A few years ago, the interest in this organization was degenerating into apathy. To cure this unhappy state of affairs Van Horn was hailed from his laboratory and asked to try his luck at revitalizing the Club. When it is considered that he was then merely a research metallurgist, spending a major share of his time on radiography, and never studied labor relations in college nor took a degree in industrial psychology, he did very well indeed. He memorized the first name of each foreman in the shop, the state of his wife's health, and the ages and accomplishments of his children, and made a point, when he had occasion to talk with any of them, to show some interest in these homely things, dear to everyone's heart. He took pains, however, never to be obvious or over-solicitous. Since nearly all the men were baseball fans, and he and his own sons are fans of the first water, he showed slow-motion moving pictures at the club meetings depicting such mysteries as "How to Throw a Curve" and "How to Slide into Second", and supplemented these by bringing groups of his major-league ballplayer friends to the meetings as guests. The latter described and demon-

strated their specialties and — being real guys — fraternized with the club members at dinner, and everyone was proud and pleased.

Pretty soon, with these and other things, the Foremen's Club began to run under its own steam. It was not the sort of work that a research metallurgist is commonly called on to do, but this didn't bother Van Horn, who says the whole experience was more than satisfying, bringing him a great many new and true friends.

Van Horn's eminent father and adored mother had a great deal to do with both his choice of a profession and his love of Cleveland. His father, Professor Frank R. Van Horn, was head of the Departments of Geology and Mineralogy at Case School of Applied Science in Cleveland and so it was not unnatural that his son should enter that school and follow the same path. The elder Van Horn, affectionately known to generations of Case engineers as "The Count", was an ardent believer in exercise. He also functioned as Director of Athletics, and apparently he gave young Kent the works, for the latter starred in football and held several track records. He has kept up his exercise ever since those days and even now, at the advanced age of 39, he plays a formidable game of tennis.

After he graduated at Case in 1926, Van Horn decided to do postgraduate work in metallurgy, particularly in non-ferrous, and so, on the advice of Zay Jeffries — a former instructor in metallurgy at Case — he went to Yale's Sheffield Scientific School to work under the famous and well-beloved Champion Herbert Mathewson. In 1928, at the urging of Dr. Mathewson, he went to Germany and spent about six months at Heidelberg University, where, incidentally, his father had taken his Ph.D. In order to learn German quickly, and especially the technical and colloquial language, he lived with a professor's family. After another year at Yale, during which he served as Sterling Research Fellow, and at the end of which he earned his Ph.D., he decided that he had been away from Cleveland long enough, so he came home and went to work for the Aluminum Co. of America, and has been with the Cleveland division — which specializes in castings and forgings — ever since.

Van Horn joined the American Society for Steel Treating (the old name of the ASM) in 1925 during his undergraduate days at Case, and with his flair for organization and leadership identified himself prominently with the Cleveland Chapter immediately on his return. His banner years there were in 1932-34, when as Chapter Chairman, he organized a study course called "Modern Metallurgy" which was free to members. As a result of this and other innovations, the membership of the chapter doubled itself, and the chapter was awarded the President's Bell (an honor that has since been discontinued in the Society) for two years straight, which was unprecedented.

Another 1932 bell-ringing accomplishment was his marriage to Estelle Yost, who is — and let there be no question about this — who is a Cleveland girl. The Van Horns have two boys, and their papa devotes much time to developing what one gathers is their already unusual athletic prowess. Aside from his family and the ASM, Kent and Estelle have two hobbies — photography and music. While neither play any instrument, their interest is so great that they are among the founders and backers of the Cleveland Civic Concert Association.

Their mutual interest in photography extends to the ability to make stills and movies in color, and the patience to spend great care and time on the technique and the composition of interesting scenes. As every one who has tried it knows, it is one thing to go on a vacation, see a gorgeous flower bed, and shoot — only to find when the film is developed that the most notable bloom was overshadowed by a mere shrub. The Van Horn's pictures are not like that.

Dr. Van Horn is a member of numerous metallurgical societies, both American and English. He has been active on the executive or other committees of the Institute of Metals Division of the American Institute of Mining and Metallurgical Engineers continuously since 1936. He is now vice-president of the American Industrial Radium and X-Ray Society. Naturally he is a leading spirit in Case Alumni Council, and has been for the last ten years. Case, Cleveland, ASM, Alcoa — that's Van Horn.

EDWARD C. McDOWELL, JR.

## Spotting the Focal Spot

THE ACCOMPANYING PHOTOGRAPH shows a small spot light, originally designed for use on spot welding machines, attached to the tube of our X-ray unit. The spot is so adjusted that, at the usual tube-to-film distance, the light falls directly below the focal spot of the tube.

This aids in the rapid setting of a series of castings to be X-rayed in the same area. It also
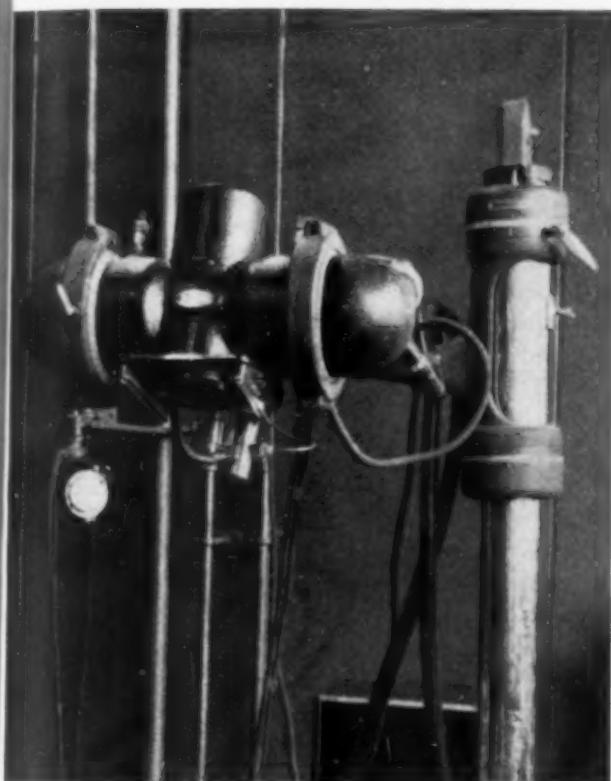


*Small Spot Light Points Location of Focal Spot of X-Ray Tube When Setting Up for Radiography*

permits rapid aligning of the tube for very large castings. The tube can easily be directed through an opening to X-ray intricate castings. Another advantage is that angle shots can be easily set up. Accurate measurement of the tube shift can be made by measuring the distance the spot travels on the surface of the casting, and this is of great value when making stereographic exposures. (ALFRED C. WOOLL, Metallurgist, Aluminum Co. of America)

## Start Exploring Jominy Bar on Soft End

HARDNESS MEASUREMENTS on Jominy bars sometimes will be low, at first, because the bar has to seat itself against the anvil. This happens even though care is taken to wipe off the anvil and the bar to be tested. If the first measurement is made at the hard end and the reading is erroneously low it might seriously affect the appraisal of the steel. This can be avoided by making the first measurements at the soft end of the Jominy bar where, if the measurement is low, the hardenability estimate is not unduly affected. Another way is to place a thin, flat piece of scrap steel on top of the Jominy bar and make one or two preliminary hardness tests on it. (GERRIT DEVRIES, Assistant, National Bureau of Standards)

## Stage for Hardness Surveys

RECENT CHANGES in certain ordnance specifications for cartridge cases require many more hardness tests than previously. The cases have been divided into zones with a minimum hardness requirement for each, readings to be taken on the Rockwell 30-T scale. It is therefore necessary to make periodic surveys of all critical areas. This involves a complete check of the cross sectional area of the shell base, taking hardness readings on $\frac{1}{16}$-in. centers.

The usual procedure is to divide the area into $\frac{1}{16}$-in. squares and measure the hardness of each. This is a long tedious task; on some of the larger artillery cases there are as many as 300 impressions on the base section alone. As this is a routine test and must be run at least once a day, it was necessary to find a shorter and more accurate method of locating the individual spots than adjusting the specimen by hand. To meet these demands a special anvil was devised to take the place of the conventional type used on the Rockwell machine.

A surface plate was prepared from a piece of hardened toolsteel, $4\frac{1}{2} \times 5\frac{1}{2} \times \frac{3}{8}$ in., ground flat to insure a solid, smooth foundation for the specimen. A threaded fitting was bolted to the underside of this plate so that it could be screwed onto the capstan screw of the Rockwell machine.

Next we appropriated a graduated mechanical stage from a Bausch and Lomb model CM metallographic microscope and fastened it to the surface plate. This stage is fitted with a spring actuated finger for holding the specimen, an arrangement which allowed a controlled transverse and longitudinal movement of the specimen by merely turning the adjusting screws. The accompanying photograph shows the device.

The micrometer scales on the mechanical stage are graduated in millimeters; and, as 1½
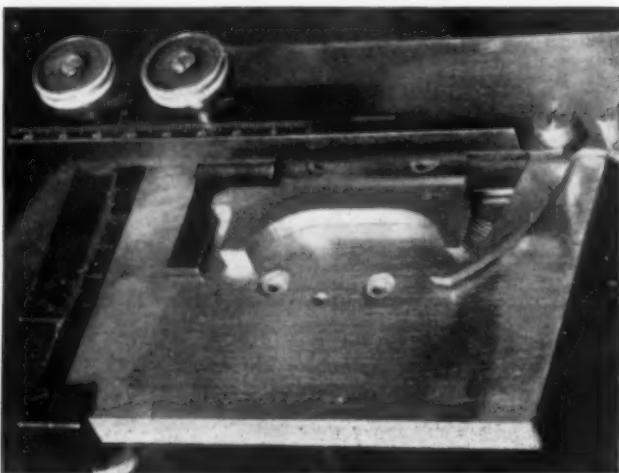


*Micrometer Stage Attached to Base Plate of Rockwell Hardness Testing Machine, Showing a Section of a Brass Cartridge Case in Place, Ready for a Hardness Survey*

mm. is equal to approximately $\frac{1}{16}$ in., the sample is merely moved 1½ divisions on the scale after each impression. By moving the specimen back and forth longitudinally, a minimum of time is lost and the observer does not become confused as to the location of the impressions. This fixture cut the operating time in half and has eliminated the scribing of squares on the specimen. All phases of its operation require no more than ordinary precautions and the accuracy of the results is very high.

We are finding the equipment adaptable to many other uses, particularly the measurement of Jominy and other test pieces for hardenability and the survey of hardness at and near welded joints. (W. W. SOPHER, Director of Chicago Metallurgical Laboratory, Rheem Mfg. Co.)

## Testing Brass Turnings for Silicon Contamination

To DETERMINE whether red brass or tin-bronze turnings, purchased for remelting into alloy ingots, are contaminated by silicon-bronze turnings, we use the following method in our laboratory. It is only qualitative but is rapid and presents no special difficulties:

A representative sample of the turnings is taken and 1 or 2 g. weighed into a 250-ml. beaker. Cover with a watch glass and add 10 ml. conc. nitric acid. Heat in the fume cupboard until no further brown fumes are evolved. Now add 10 ml. perchloric acid (70%) and evaporate to dense white fumes. Allow to cool, add 10 ml. conc. HCl and bring to a boil. Dilute to about 125 ml. with hot, distilled water and boil for about 5 min. Tin or lead will remain in solution and will thus not interfere with the test. A precipitate of silica can easily be seen, if present, confirming any suspicion of contamination. (M. R. BERKE, Chemist-in-Charge, McKay Smelters, Ltd.)

## Beaded Glass Screen for Viewing Microstructures

DURING THE STUDY of particularly interesting or unusual microstructures, it has sometimes been found advantageous for all interested parties in the metallurgical and engineering departments to examine the specimen and discuss the matter thoroughly. In order to speed up these examinations, the metallurgical department of the Fort Wayne Works, International Harvester Co., utilizes an 18 by 18-in. beaded glass screen as an attachment on the metallograph. This permits public examinations of the specimen in question and enables all the investigators to see the same field under discussion.

The screen is mounted on a saddle stand consisting of a vertical steel rod and an adjustable fixture designed for its support. This arrangement permits the screen to be raised or lowered on the rod to any desired height. By means of an adjusting screw on the saddle stand, the screen may be extended along the centimeter scale on the prismatic optical bench of the metallograph to any predetermined magnification.

In order to produce a bright image, we have

substituted distilled water for the green filter solution normally used.

Further uses for the screen have been found in the determination of case depths. It is only necessary to project the micrometer scale on the screen and select the desired location for reading. The screen has also been useful in the examination of steels for grain size. (J. D. WALKER and J. J. TAKACA, Metallurgists, International Harvester Co.)

## Pen Cleaners for All (Who Have Hair)

THERE ARE thousands of automatic recorders in the metallurgical industries for temperature, pressure, or other conditions, and probably millions of pen cleaners (very fine wires about 0.005-in. diameter or less). However, it seems that nothing is so rare as a pen cleaning or priming wire when a recording pen actually fails to write.

To remedy this it was found that a hair plucked from a human's head works wonders. This should eliminate practically all the excuses for dry pens (when ink is available) and at the same time furnish a good excuse for baldness! (A. L. HODGE, Research Metallurgist, Carnegie-Illinois Steel Corp.)

## Stamp for Marking Jominy Test Bar

THOSE using the Jominy test for routine or research checking of hardenability are troubled in accurately locating the Rockwell impressions. Of the methods advanced, one is to use a micrometer arrangement, in which a certain number of turns on the screw represents a definite transverse travel under the Rockwell penetrator.

During the past year and a half, we have been using a much simpler device, merely a rubber stamp (the impression of which is shown alongside, full size) to place ink
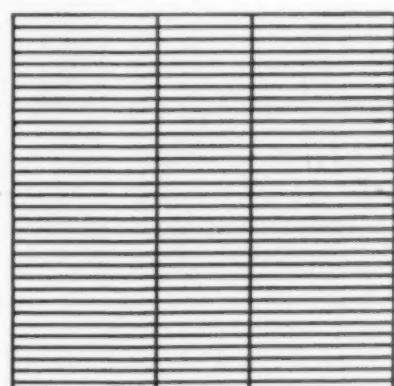
lines one sixteenth of an inch apart on the hardened Jominy specimen.

The two vertical lines near the center are merely two rubber strips present to reinforce the horizontal markings and consequently maintain more accurate spacings.

Inasmuch as the rubber stamp can be used for accurate spacing in most types of hardness versus transverse distance determinations, we believe it to be a valuable asset to the metallurgical laboratory. (HOWARD B. MYERS, Metallurgist, McConway & Torley Corp.)

## Three-Piece Mortar Shells Replace Forgings

CONVERSION from a forged body for 4.2-in. mortar projectile to one made of three pieces — a short length of X-1335 seamless steel tubing, a base plug and a nose adapter, all three silver soldered (brazed) together — has been a big factor in increasing the output of badly needed ammunition. Forging machines were unnecessary and much metal is saved.

Localized heating is done in one 50-kw. and one 40-kw. Tocco motor-generator induction machine, producing current at 9600 cycles. Base plugs are dipped in "Scaifflux" (which obviates the need for acid or alkaline reagents in subsequent cleaning), a ring of $\frac{3}{32}$-in. silver solder wire snapped into a recess, and the base is fitted by hand into the tubing. Two assemblies are placed in a double inductor, clamped down by air cylinder, and heated. Brazing cycle is 56 sec.; 38 sec. is required to cool from temperature (1400° F.). Similarly, nose adapters are silver soldered into the tapered end of the tube, two at a time, in a 38-sec. heating cycle.

All shells are tested with internal pressure in manufacturing routine to check for tightness. Any rejects from the pressure test can readily be disassembled by reheating to brazing temperature, and practically all rejects can be reclaimed by removing the cause of the original leak — usually a speck of foreign matter of some sort. Such reclaimable rejects are less than one in 400. (JOHN Y. BLAZEK, Vice-President, Lempco Products, Inc.)

# BITS AND PIECES

## Hardness Test Separates Zinc From Cadmium Anodes

HERE'S an addition to the ever growing list of quick methods of separating metals that look alike:

Several tons of cadmium and zinc anode balls became mixed. Some of the cadmium balls had been used and plating solution had dried on them, resulting in a generous amount of cadmium bearing dust covering all of the balls. Separation by chemical spot testing without thorough washing, was therefore a rather questionable proceeding.

We found a rapid and easy solution to our problem by hardness testing. Cadmium balls have a Brinell hardness number of 19 to 21 (500-kg. load) while the zinc balls were in the 44 to 48 range. Thus either a Brinell or Rockwell testing machine accurately determined the identity of each ball. (A. A. BRADD, Laboratory Director, Remington Rand, Inc.)

## Nesting Tight Loads of Awkward Shapes

A LITTLE INGENUITY in nesting awkward shapes can sometimes result in a notable increase in furnace load. This is shown by the two accompanying photographs. The original scheme, at left, was supposed to put 70 small welded assemblies (chain devices on tracks for amphibious tractors) into a standard Homo furnace so they could be stress relieved at 800° F. Actually only 64 pieces could be so loaded, for the containers were a little out of round and the perforated bottoms slightly bulged. By rearranging the method of stacking, working it out like a Chinese puzzle, 100 pieces could be fitted into the container. At production rates of 4500 assemblies per day, this enabled us to divert one furnace completely to other important work. (CLIFFORD ALEXANDER, Heat Treater, Link-Belt Co.)

## Identifying Specimen Mounts

A PRACTICAL, inexpensive and everlasting method for identifying metallurgical specimens mounted in transparent plastic such as lucite is evidently being sought by metallographers. We use the following procedure:

1. After the metallurgical specimen has been sufficiently covered with lucite or other similar transparent plastic, insert a stiff paper strip — cut from index cards — coded with ink or pencil, and cover paper strip with a thin layer of the plastic before compression.

2. Complete the mount according to directions for the particular plastic in use.
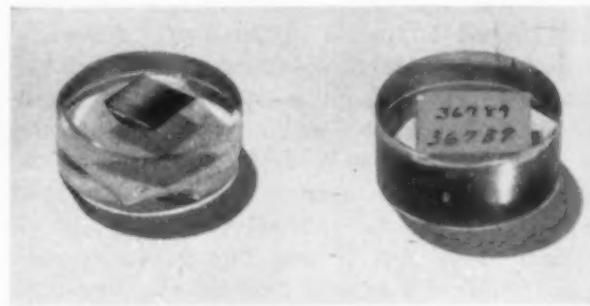


As shown in the view, the small stiff coded paper strip will appear in plain view embedded in a protecting layer, safely protected from moisture and air. (WILLIAM KOPPA, Chemist, International Harvester Co.)



*Original and Revised Nesting Scheme That Increased Furnace Load From 64 to 100 Pieces*

# ROCKWELL HARDNESS

# (DIAMOND PENETRATOR)

# OF CYLINDRICAL SPECIMENS

By W. L. Fleischmann
and R. S. Jenkins
Fort Wayne Works
General Electric Co.

$I$T IS COMMON PRACTICE to apply a static hardness test for the determination of some properties of metallic materials. The hardness test has become of engineering significance, since data have been developed correlating hardness values with certain properties — in particular, tensile strength.

The "Rockwell" Hardness Tester using a diamond penetrator, pressed into the sample under 150-kg. load, and results read on the so-called C-Scale, is without doubt the most commonly used on heat treated steels. (In this article it will be denoted as an $R_C$ reading.) In many cases, the $R_C$ hardness is specified for cylindrical parts, and sometimes their shape is such that the hardness cannot be taken on a flat end of the specimen. Therefore, it would be necessary to mill or grind one or preferably two parallel flats on the part. This constitutes an extra operation or, worse, it may make the part useless. Engineering specifications were formerly not as strict, but since a multitude of equipment is now being built with unit stresses ever closer to the limit of the yield of the materials, it has become necessary to reconsider the testing procedure with a more critical eye to make sure that the readings taken are in conformance with the intentions and limitations of the test procedure.

It is well known that the Rockwell hardness measurement on a cylindrical surface is not the same as on the flat, and to allow the factory to take Rockwell measurements on cylindrical sur-

faces, it was necessary for us to establish a correction which would correlate the hardnesses taken on the two.

To determine the error caused by measuring $R_C$ hardness on the cylindrical surface, a series of cylindrical samples of various sizes and hardnesses was checked. The samples were small cylinders, accurately machined to size, and the end surfaces machined parallel. Samples were machined from an oversized bar of chromium-molybdenum steel (S.A.E. 4140) and from one of its alternates, the triple-alloy NE9442. Five diameters, which include the most common sizes used in General Electric's Fort Wayne Works, were selected in accordance with the No. 10 series of preferred numbers, which gives equal spacing between the different diameters, thus allowing ready interpolation. Diameters tested were 0.250, 0.315, 0.400, 0.500, and 0.630 in.

The cylinders were oil quenched out of a salt bath to avoid decarburization and tempered to these different values of $R_C$ hardness (measured on the flat): C-25, C-30, C-35, C-40, C-45, C-55.

From three to eight readings were taken along the cylindrical surface and across one end. All in all, 96 samples were checked, which involved taking approximately 850 readings. On hardness readings below C-20, and on small diam-

**Fig. 1 — *Average Hardness (Rockwell C-Scale) of Cylindrical Versus Flat Surfaces. Points are averages of several readings on single specimen***



eters, the readings showed considerable spread and the method of least squares was applied to obtain the average of the readings and with it the position of the lines in Fig. 1.

With large diameters or high hardness, the measurements taken on the cylindrical surface approach the reading obtained on a flat. This leads to the theoretical conclusion that the readings taken on one diameter at different hardness values should follow a hyperbolic curve. Hence, the curves shown in Fig. 1 should be hyperbolas. However, the curvature is so slight within the range investigated that a straight line can be considered representative and is accurate enough for all practical purposes. These general conclusions agree well with the data published in 1939 by W. E. Ingerson in Bell Telephone System Technical Publication, Monograph B-1229: "Correction to be Applied to Rockwell Hardness on Cylindrical Specimens Ranging in Diameter From Two to 16 Times the Penetrator Diameter", in which the author discusses the hardness measurements when using a $\frac{1}{16}$-in. ball penetrator on annealed and relatively soft metals.

We then plotted the lines of Fig. 1 in different parameters. Figure 2 gives $R_C$ hardnesses measured on cylindrical surfaces versus a correction factor to make them correspond to readings on a flat. Figure 3 plots the diameter of cylinder versus correction factor. Both graphs show that the readings follow one pattern. In particular, the curves in Fig. 3 show that a general relationship exists for values of correction factor versus diameter of cylinder, which means that all curves can be represented by a hyperbolic equation. Consequently the nomograph of Fig. 4, which eliminates the necessity of interpolation of the test data, has been constructed. It can be used with confidence in its accuracy to within the limits of the test

**Fig. 2 (at Left) — *C-Scale Readings on Cylindrical Surfaces of Various Diameters Plotted Against Plus Correction to Make Them Correspond With Hardness as Measured on the Flat. Fig. 3 (at Right) — Correction Versus Cylinder Diameter at Constant Hardness on Flat***

data, the accuracy of the latter, in turn, being determined by the accuracy and adjustment of the Rockwell testing machine.

In the example shown by the cross line in Fig. 4, a 0.460-in. cylinder measured C-49; the correction is +2 units, making the true value of the hardness of the part C-51.

Although the technique of the Rockwell test on cylindrical surfaces is in no way different from the testing on the flat, certain general precautions should be observed: If the Rockwell hardness of the round specimen is found to be below C-20, exact results cannot be expected because it is outside the accuracy range of the machine. The axis of the cylinder should be normal to the axis of the penetrator, that is, the piece has to be accurately centered. It should be obvious that it is useless to take Rockwell hardness on a cold rolled piece of steel at the surface, as the hardness will vary across the diameter. Lastly decarburization has to be carefully avoided, else the soft surfaces will mask the correct hardness of the sub-surface metal. ●

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Fig. 4 — *Nomograph for Finding Correction to be Added to the Rockwell C-Scale Reading on a Cylindrical Surface of Any Diameter to Convert it to the Hardness as Read on a Flat*



Lay straight edge across chart through measured values of hardness (e.g. C-49) and cylinder diameter (e.g. 0.460 In.), and read the correction at the point of intersection of the correction line (e.g. +2).
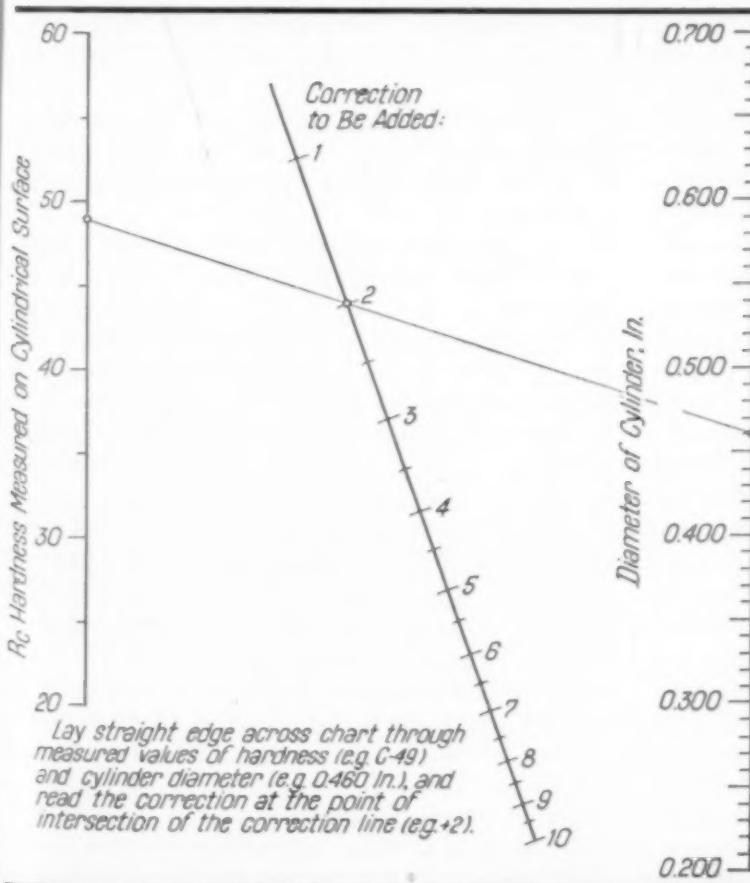
# CENTRIFUGAL

# STEEL CASTINGS*

By L. Northcott and D. McLean

CENTRIFUGAL CASTINGS of tubular shape 6½-in. outside diameter and about 1¾-in. wall thickness were made of a nickel-chromium-molybdenum steel of the following composition: 0.30% C, 0.28% Si, 0.64% Mn, 2.9% Ni, 0.60% Cr, 0.50% Mo. Some were cast "hot" (2850° F.), others "cold" (2750° F.) — the liquidus of the steel being about 2650° F. The rotating mold had its axis horizontal and the speed ranged, for different casts, from 450 to 1700 r.p.m. Pouring time for a 65-lb. casting ranged from "very rapid" (5 sec.) to "very slow" (75 sec.) — "normal" being about 12 sec. The castings were cut transversely at mid-length and three distinct types of structures observed, of the same fundamental nature as those found in similar nonferrous castings.

Type I structure is composed of three sharply defined zones differing in purity and crystal structure. The outer zone is thin, of chill crystals of medium purity, merging into fine columnar crystals inclined in the direction of rotation of the mold. Owing to the rapid chilling its composition is slightly purer than the melt. The middle zone starts to form at commencement of "splashing", or tmbling of the portions of the unsolidified metal which continually bring it back to its starting condition of no rota-

# COPPER PLATE

## AS A STOP-OFF

## WHEN NITRIDING

By W. V. Sternberger
Chief Metallurgist
Motor Products Corp.
and E. R. Fahy
Chemical Engineer
United Chromium, Inc.
Detroit

VARIOUS COATINGS have been used in the past for selective "stopping-off" against nitriding. In tests recently carried out the authors found that copper, deposited under controlled conditions to give a dense non-porous plate, is effective. Before describing the tests that were made a summary of other methods commonly used may be of interest.

Probably the most widely used stop-off has been electrodeposited or hot dipped tin approximately 0.0003 in. thick. While tin is effective it has certain disadvantages, the principal one being that tin melts at temperatures below those used in nitriding. This disadvantage can be minimized by applying thin deposits since such deposits show little or no tendency to flow at furnace temperatures, due probably to surface tension effects and to an actual alloying of the bulk of the tin with the basis metal. However, if tin is applied in too heavy a layer flow occurs, and the tin may spread out over surfaces it is not intended to protect.

A second characteristic of a tin deposit, disadvantageous in some instances, is that it is very difficult to remove later by electrochemical or chemical methods, due probably to the tin-iron alloy that is formed.

Certain tin base paints and also paints of other types have been developed specifically for stop-off use in nitriding. As a rule they may do the job at somewhat lower cost than other methods. Disadvantages include difficulty of applying a uniform coat, regardless of method of application. Too thin a coat is ineffective; too thick a coat, as in the case of tin, may sometimes lead to flow of the material onto significant areas. Some stop-off paints are baked after applying

and flow may also occur during the baking operation, necessitating the removal of the flowed material.

A third coating which has been used to limited extent is nickel plate, but there appears to be but little information available regarding it as a stop-off.

Copper plate has received but little consideration from metallurgists for this use. It has been tried at various times and such information as the authors have had available has been conflicting as to the results obtained. Instances of successful use were however cited by J. J. Pawlik of the Continental Motors Corp. in an address delivered several years ago before the Detroit Section of the American Electroplaters Society, and at a later date he cited experience to show that a copper plated article which can withstand immersion for 24 hr. in boiling water without showing signs of rust is an effective stop-off coating for a 72-hr. nitriding cycle.

The tests made by the present authors were carried out with the purpose of determining whether copper would be a satisfactory stop-off for certain bushings nitrided in production in the plant of Motor Products Corp. of Detroit. To start with, a number of "Nitralloy G" bushings were copper plated using the J. E. Stareck's

"Unichrome Copper Plating Process", described in U. S. Patent 2,250,556, then nitrided, and finally tested for penetration of the copper plate by nitrogen. Tests of the processed parts were carried out in the laboratory of Motor Products Corp., and indicated that no penetration of the copper had occurred. The bushings then were forwarded to V. O. Homerberg, technical director of the Nitralloy Corp., and he confirmed the fact that the copper had functioned effectively.

This initial set of bushings was run as a preliminary test only; each had a copper plate close to 0.001 in. thick on the significant surfaces.

To establish definite, satisfactory operating conditions in plating, and also to determine if possible the minimum plate for protection during a given nitriding cycle, a second series of tests was run wherein a number of bushings were copper plated in the Detroit pilot plant of United Chromium, Inc., owner of the Stareck patent, using the following procedure:

The bushings were racked, degreased in vapor, rinsed in water, dipped for several seconds in a 50% by volume solution of muriatic acid, and again rinsed in water, cleaned anodically in an alkaline electrocleaner, rinsed in water, and given a "strike" deposit (30 sec.) in a cyanide copper solution. Following the strike the bushings were water rinsed thoroughly, and then plated with definite thicknesses of copper.

The "Unichrome Copper Solution" was operated at an average overall current density of 60 to 65 amperes per sq.ft., and at a temperature of 135° F. The actual plating speed on the significant areas of the bushings as determined by Magne-Gage measurements was 0.001 in. per 17 min., and each bushing was plated for the time necessary to give the particular thickness which was required.

The bushings then were nitrided for 72 hr. at 965° F.

Following nitriding the surfaces were measured for Rockwell hardness, and their cross sections thoroughly examined under the microscope to determine if the copper had been penetrated. Test results, as reported by Dr. Homerberg together with thicknesses of copper plate deposited before nitriding, are listed in the table. Original surface hardness of each bushing was approximately 70 on the Rockwell 15-N scale.

It was evident from these tests that copper plate deposited under the conditions specified was of sufficient density to protect effectively the steel surface during the nitriding cycle used. It appears also to be a fact that the copper must be deposited under conditions that will result in a deposit sufficiently non-porous to resist the nitriding cycle in question. Such conditions have been outlined in this paper for the 72-hr. cycle at 965° F., and a second series of tests proved the same conditions satisfactory for 154 hr. at 970° F.

The minimum thickness of copper plate effective for the 72-hr. cycle at 965° F. was surprisingly low, that is to say, 0.0004 in. It should however be borne in mind that on a production run 0.0008 in. might well be specified to insure a factor of safety covering uneven plate distribution. In the tests using the 154-hr. cycle at 970° F. a thickness of 0.0008 in. copper proved to be satisfactory. A lesser thickness might also have been satisfactory, but for this particular cycle no attempt was made to determine the *minimum* thickness to protect the underlying metal.

### Data on Test Bushings

| BUSHING | COPPER PLATE | HARDNESS | REMARKS |
|---|---|---|---|
| No. 1 | 0.0002 in. | 92.5 | 0.012 in. case |
| 2 | 0.0004 | 70 | No case |
| 3 | 0.0006 | 68 | No case |
| 4 | 0.0008 | 69 | No case |
| 5 | 0.0010 | 72 | No case |
| 6 | 0.0012 | 69 | No case |

There are two procedures by which the copper plate itself may be confined only to the areas it is intended to protect. One involves plating over-all and then grinding copper off the surfaces to be nitrided. The second procedure involves stopping-off the surface to be nitrided by commonly used lacquers or non-conducting masks, then depositing copper on the areas to be protected against nitriding, and finally removing the lacquer or mask from the areas to be nitrided.

It also should be borne in mind that the surface finish prior to copper plating is a factor of importance. The bushings which we tested were rough ground on a Norton 3746-K-5 wheel (46 grit). While comprehensive data are lacking from which specific conclusions can be drawn as to the surface finish required, the general statement can be made that the surface to be protected should be free from scale and should be finished to such an extent as to insure the complete deposition of a dense, non-porous copper plate.

Advantages of copper plate as a stop-off in nitriding include ease of application, and also ready removal after it has served its purposes. The plate may be ground off or removed by electrochemical or chemical methods.

Disadvantages are not apparent at the moment. From the cost angle the use of copper plate would probably be more economical than the use of either tin or nickel, and somewhat less economical than paint. ◉

## Unsolved War Problems

WASHINGTON, D. C.

*To the Readers of* METAL PROGRESS:

Metallurgists may be of assistance to the Navy Department, which is seeking solutions of the following four problems. Suggested solutions should be prepared in sketch and description form and sent to the National Inventors Council, Department of Commerce, Washington 25, D. C., for consideration and report:

1. *A cheap and effective barrier* to prevent the propagation of cracks in steel structures, without making use of riveted seams and the caulking incidental thereto.

2. *A method of welding high pressure piping* without the aid of backing straps or with back straps which would be soluble in a harmless solution which could be introduced in the pipe before putting same into service.

3. *A method of measuring the elastic stresses* locked up in steel or other metallic structures at and beneath the surface of the material without having to dissect the structure in order to record the elastic recovery which results from isolating various segments.

4. *A method of welding light gage aluminum.* This is of particular interest since aluminum lifeboats and life rafts are currently of riveted construction due to the lack of a satisfactory commercial method of welding.

CHARLES F. KETTERING
Chairman, The National Inventors Council

## Pit Corrosion of Magnesium Alloy Castings

CLEVELAND, OHIO

*To the Readers of* METAL PROGRESS:

We wish to comment on the letter from J. L. Miller appearing on page 752 of the October 1944 number of *Metal Progress* in which a quotation is made from our booklet "Magnesium Data 1943" to the effect that magnesium alloys have excellent resistance to ordinary atmospheres over long periods of time. We believe this to be an accurate statement.

The conditions cited by Mr. Miller which caused damaging pits in a winter's outdoor storage do not constitute what is ordinarily termed "atmospheric exposure" but rather simulate a test conducted by alternate or constant immersion in the corroding medium. Mr. Miller's photograph showing undamaged portions of the casting where drainage has been adequate proves that bare magnesium alloy has good resistance to atmospheric corrosion in the usual sense, and we have a great deal of evidence to justify the statement in our literature.

The chemical analysis of the corrosion product given in Mr. Miller's letter also indicates to us that these castings have not been exposed in what would properly be called "an ordinary atmosphere". Chloride and sulphate contents are abnormally high even for an industrial atmosphere and it would appear to us that they may be coming from some abnormal source. A chloride content of approximately 0.75% would be expected to corrode a magnesium casting but the puzzle in this case is the source of the salts. That they have not come from the casting itself is indicated by the pitting on only the submerged surfaces and the freedom from corrosion of the other portions of the casting.

W. G. HARVEY
American Magnesium Corp.

## Special Practices Required for Maximum Damping Capacity

SHEFFIELD, ENGLAND

*To the Readers of* METAL PROGRESS:

Whether or not a high damping capacity is a desirable attribute of steel to be used for some particular purpose is a question which the engineering profession does not yet answer with unanimous voice. In this note I shall not discuss the question but merely point out that should steel be required to have this property in as great a degree as possible, then it seems probable that special precautions will be necessary in the preparation of the bars, forgings or other articles needed. This at least appears to be a legitimate deduction from data given in a paper entitled "Further Experiments on the Damping Capacity of Metals" by W. H. Hatfield, L. Rotherham and E. M. A. Harvey before the North-East Coast Institution of Engineers and Shipbuilders in March of 1944. These data show that prior cold work reduces very considerably the damping capacity of steel; thus, tests on a mild steel bar before and after normalizing followed by various

amounts of cold drawing gave the results shown in the table below.

The authors of this paper were led to investigate the effect of prior cold work because in experiments previously carried out and reported in an earlier paper (see also *Metal Progress* for October 1943, p. 643) they had found wide discrepancies between the damping capacities of different commercially produced bars of the same type of material. The chance heating of one of

### Relation Between Damping and Previous Cold Work

| TREATMENT | DAMPING PER CYCLE | | | | AVERAGE REDUCTION DUE TO COLD WORK |
|---|---|---|---|---|---|
| | 4500 PSI. STRESS | 6750 PSI. STRESS | 9000 PSI. STRESS | 11,400 PSI. STRESS | |
| Normalized Only | 1.92% | 2.24% | 2.64% | 3.00% | .. |
| Cold drawn 5% | 1.48 | 1.76 | 1.92 | 2.16 | 25% |
| Cold drawn 10% | 1.12 | 1.36 | 1.70 | 1.98 | 37½ |
| Cold drawn 25% | 0.60 | 0.72 | 0.78 | 0.88 | 70 |

these bars to 1100° F. — which caused it to bend appreciably — had given the clue that these discrepancies might have resulted from differing amounts of cold work which the individual bars had received during their ordinary processing in the steel works. For further investigation, several of the bars concerned were re-tempered in the laboratory and their damping capacities re-determined. The results obtained were highly interesting.

For example, four different bars of stainless iron, containing 0.09 to 0.10% carbon and 13.1 to 14.0% chromium, had previously given values, respectively, of 3.92, 1.80, 1.38 and 4.00% damping per cycle at a stress of 4500 psi. These bars had been heat treated in the works in the ordinary way, tempering being done in all cases at 1365 to 1380° F. After they had been re-tempered in the laboratory at the same temperature, their damping capacities rose to 11.52, 11.36, 9.92 and 10.04% per cycle, respectively, under the same testing conditions. Similarly a marked improvement in damping capacity was noted when several commercially produced, hardened and tempered bars of stainless steel (0.25 to 0.30% carbon, 12.0 to 14.0% chromium) were re-tempered in the laboratory though, in this case, the divergencies between the properties of individual bars were not reduced in so thorough a fashion.

If it be assumed that these low and widely divergent values for the damping capacity of the commercially heat treated stainless iron bars were actually due to the different amounts of cold work (for example, cold straightening) which the individual bars had received during their final processing — and the authors of the paper appear to hold this view — it seems obvious that when such material is required by the user to possess high damping properties, its production must be so managed that the bars, forgings and other forms in which it is to be supplied are substantially stress-free.

That is not necessarily the end of the matter. The steel maker's product is frequently the raw material for the engineering workshop, and if the steel is to retain the high damping properties that the maker has taken pains to bestow on it, then subsequent handling in the shop must also be the subject of careful study. An example can be taken from turbine blading where very large quantities of stainless iron are used. Should this prove to be a situation where high damping capacity is desirable, it is obvious that suitable precautions will have to be taken to insure that the methods used for preparing the finished blades from the blading bar supplied by the steelmaker, and for fixing them firmly in position in the turbine casing or rotor, do not result in the inserted blades being in a more-or-less cold worked and internally stressed condition. One can imagine that some methods used by turbine manufacturers during fabrication and mounting might easily produce internal stress and thus result in the inserted blades having damping capacities at considerably lower levels than that of the carefully heat treated material.

J. H. G. MONYPENNY
Chief Metallurgist,
Brown, Bayley's Steel Works, Ltd.

EDITOR'S NOTE — Mr. Monypenny is well known professionally by American students and users of the high chromium alloys, since his book "Stainless Iron and Steel" was the first reasonably complete account of this important new family of alloys to be published (1926). The greatly enlarged second edition has now been available for many years and is a mine of information on those varieties of the heat and

*J. H. G. Monypenny*

corrosion resisting chromium-nickel steels that are in regular production in England. *Metal Progress* has been especially fortunate in having frequent letters from him in the correspondence pages, discussing topics of current interest to English metallurgists. After some urging, he responded to a request with the above portrait. He writes that his personal interests are largely in the steel works, and in the fortunes of his two sons, both of whom are officers in the British army.

## "Available" Beryllium Reduced by Internal Oxidation

PITTSBURGH, PA.

*To the Readers of* METAL PROGRESS:

The interesting article entitled " 'Available' Beryllium in Copper" by H. G. Williams, appearing in the July issue of *Metal Progress,* fails to mention the possible loss of age-hardenability through the internal oxidation of beryllium. Where copper-beryllium alloys are heated in a very mildly oxidizing environment the conversion of beryllium in solid solution to a precipitate of

beryllium oxide proceeds at a very rapid rate. Metal so handled ceases to be age-hardenable. Even where the alloy has not been subjected to especially high temperatures, but where the cross-section is small, the oxidation of beryllium may be serious. Thus the production of powdered metal alloys from copper-beryllium powders has met with difficulty, apparently because the beryllium in the powder oxidizes with great ease. I have found in the course of a few brief experiments that the age-hardening characteristics of copper-beryllium powder alloy can be partially restored by heat treatment in dry hydrogen at a temperature just below the solidus, but complete restoration of the properties does not seem to be attained.

FREDERICK N. RHINES
Assistant Professor of Metallurgy
Carnegie Institute of Technology

## Damage to Copper Wire by Molten Solder

NEW YORK CITY

*To the Readers of* METAL PROGRESS:

Insulated copper wire must of course be cleaned before joints or terminals can be soldered. In coarse sizes this is readily done with a knife or a stripping tool. Fine wire (30 to 40 gage) used in instruments and tubes is usually covered with synthetic resins, frequently of the "Formex" type, and this can be removed in a few seconds by mere immersion in molten solder at temperatures of 930° F. or higher. The insulation apparently serves as a flux to permit "tinning" of the copper wire in the same dipping operation. More positive and complete stripping and tinning are obtained at slightly higher temperatures, 1025 to 1100° F. For example, in the small wire sizes of No. 29 H.F. (Heavy Formex) and No. 40 H.F., the action is completed in about 10 and 5 sec., respectively, both at about 1050° F.

It is common knowledge that if the wire is kept in the hot solder long enough, the submerged section is completely eaten away. "Long enough" is an inadequate expression here; for No. 29 H.F. wire it represents about 20 sec., and for No. 40 H.F., 5 to 6 sec. The leeway for No. 29 is relatively appreciable, but not for No. 40 wire. For example, No. 40 H.F. will not properly strip and tin below 3 sec., and although stripping-tinning action may be held through close control to the

minimum time required, *some* copper loss can be expected. Higher temperatures, up to 1175° F., reduce the minimum dipping times, but also shorten the destruction times; No. 40 H.F. is destroyed practically as soon as the stripping and tinning are completed.

This phenomenon in wire destruction is important and serious. Such reduction in diameter in hot tin dipping means weakened leads, perhaps production losses either at the dipping operation, or later in assembly, and an inferior product that fails in the field. This is especially true in the finer wire sizes.

To avoid this trouble Fairchild research engineers have devised a means of stripping wire by dipping successively in two chemical solutions that have no action on the wire. However, even clean wire is attacked by molten solder and some preliminary tests to determine optimum soldering conditions were made. The results are of general interest.

All cleaned wire test specimens were bent into a standard hairpin shape with one longer leg bent outward at right angles near the end opposite the loop. The specimens were handled by this projection. They were plunged, loop down, into the molten solder, only deep enough to permit the free side of the hairpin to remain out of the solder to about one-half its length. When this vertical projection fell over, due to the destructive action of the solder at the bend, the test specimen was considered destroyed, as the wire was so eaten away as to be incapable of supporting even this small weight.

The wire life or destruction time was measured accurately from the moment of entry into the solder. The solder was under temperature control and dross was scraped from the surface immediately before each test.

Results for 40:60 tin-lead solder ("soft solder") and 60:40 tin-lead solder ("hard solder", so-called) are shown in the drawing below. Similar tests were made in pure lead. Copper goes into solution in lead very slowly at temperatures of 800° F. or lower — the test values being 50 to 80 times as long as for 40:60 solder; and at the higher temperatures some 4 times as long for the finer wires. However the pure lead solder joint is not strong mechanically.

A review of our tests leads to the following
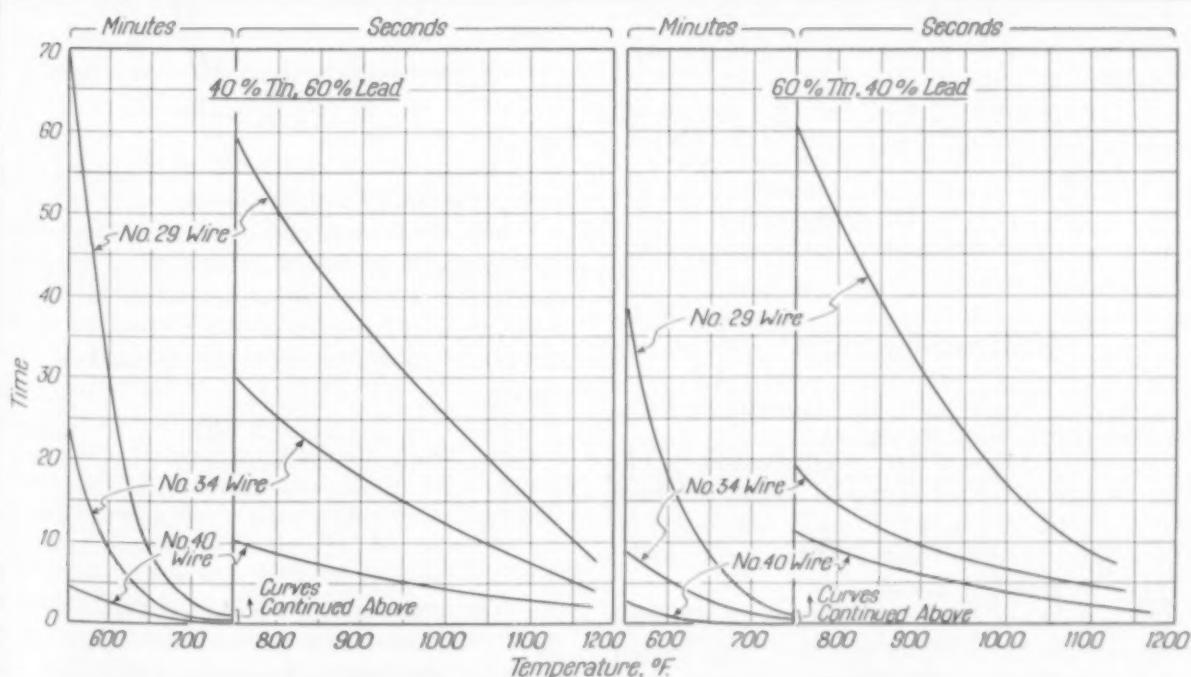


*Time Versus Temperature for Destruction of U-Bends of Fine*
*Copper Wire in Molten Solders (40:60 and 60:40 Tin-Lead)*

conclusions as to the surface damage done to fine wire by the soldering operation, resulting in loss of fatigue strength and toughness, and in severe cases in undersized wire and deficient tensile strength:

1. The life and diameter of any fine copper wire in any solder is decreased with increasing molten solder temperatures.

2. The higher the tin content of tin-lead solder, the shorter is the life of a given wire in that solder for any given solder temperature.

3. For a given solder composition and solder temperature, the finer the wire size (diameter) the shorter is the wire life in the solder.

The all-around best solder of those tested appears to be the 40:60 combination, commonly referred to as "soft solder". Other solders of this type analysis may offer even better properties. For certain other purposes, regardless of these findings, hard, or 60:40 solder, may be best.

On the basis of these facts only, it is apparent that a low solder temperature should be used for tinning or making joints on wire sizes finer than No. 30. Preferably, these solder temperatures should be kept either within 150 to 200° F. above the melting or liquid point of the solder used, or under 600° F. For Formex or Formvar coated wires, a low temperature insulation stripping method other than the hot tin dip method now becomes necessary. Other methods, involving high temperatures, such as the gas flame method, tend to embrittle and oxidize the copper, and are no better.

C. A. HARRISON
Vice-President,
Fairchild Camera & Instrument Corp.

## Silitoss-Gruppo

PALMERTON, PA.

*To the Readers of* METAL PROGRESS:

Frequently foundrymen are disturbed by the actions of the *Silitoss-Gruppo* (sand slinging gremlin). This is an extremely uncommon species of the gremlin family and is very rarely entrapped in freezing metal.

The adjoining photomicrograph of a metal surface reveals an unlucky one that was caught during solidification. This rare specimen was discovered by J. L. Rodda of Palmerton, Pa. He is also very small, for the bellows extension went out to 500× before the rough outline of his
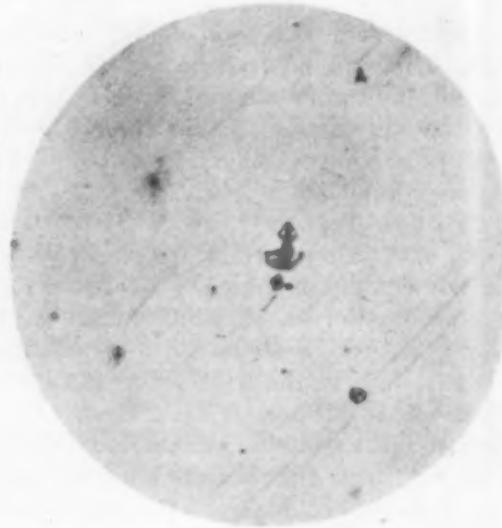


*Silitoss-Gruppo* × *500*

anatomy was revealed. He seems to be holding on to his hat for dear life; perhaps if it could removed — possibly by alpha ray bombardm — his charm would vanish.

E. J. BOYLE
Research Division
The New Jersey Zinc

## Spectrographic Boron Steel Standards

WASHINGTON, D. C

*To the Readers of* METAL PROGRESS:

Industrial importance of addition agents steel containing boron among the essential e ments has led the National Bureau of Standa to furnish six samples of boron steels in rod for for spectrographic standards, as follows:

| NUMBER | KIND | TOTAL Bo |
|--------|------|----------|
| 425 | Mn-Ni-Cr (NE 9450) | 0.0006% |
| 426 | Cr-Mo (S.A.E. 4150) | 0.0011 |
| 427 | Cr-Mo (S.A.E. 4150) | 0.0027 |
| 428 | Mn-Cr | 0.0059 |
| 429 | Ni-Cr-B | 0.0091 |
| 430 | Ni-Cr-B | 0.019 |

The standard samples are cylindrical r $\frac{7}{32}$ in. diameter and 4 in. long (approximat 22 g.). The 4-in. rod may be cut at the cen for use as self electrodes. The price per sam is $3.00.

LYMAN J. BRIGGS
Director, National Bureau of Standa

## Salvage of Aluminum Scrap

SOMEWHERE IN FRANCE

*To the Readers of Metal Progress:*

[EDITOR'S NOTE — This letter was received last summer along with the one published in October. In response to letters forwarded to France as soon as commercial communications were resumed, Professor Portevin has cabled that he is sending some information about the present condition of the French metallurgical industry by a mutual friend, about to depart for the United States.]

Restrictions and absolute prohibition of the use of important metals in France during the last few years has had two results — first, a search for new and better alloys of available metal [as was noted for zinc in the October issue of *Metal Progress*] and second, the salvage of worn out pieces of metal, industrial waste, and wrecked war matériel and munitions. The last category is of greatest importance, especially for the light aluminum alloys salvaged from wrecked aircraft.

The secondary metal industry has for years been an important source of usable metals, especially iron and copper. A large proportion of foundry iron is cupola melted scrap; likewise much secondary brass and bronze, recast into ingot, goes to the non-ferrous foundry. However the utilization of secondary aluminum has not been as extensive in France as it has apparently been in America. Whatever the commercial reasons for this difference in practice in the two nations, it is clear that the remelting of aluminum alloys involves an entirely different set of physico-chemical considerations.

In the case of iron and steel scrap the presence of some rust is of no importance. If the metal being melted had no oxide on it, the melting conditions would have to be arranged to produce some, for iron oxide is a powerful reagent for eliminating other impurities, metallic and non-metallic, which exist in the charge of scrap metal. Much the same thing is true of the fire refining of copper alloys, a process which may be looked upon as a melting under oxidizing conditions, and then a reduction of the surplus copper oxide by charcoal or by poles of wood thrust into the molten bath.

However, aluminum has a stronger affinity for oxygen than the other metals — copper, silicon, manganese, zinc, iron — with which it is alloyed. The very melting may be considered an oxidizing action. The result is that the product is often an alloy of mongrel composition, of little practical value.* To correct this situation four measures are being taken:

1. Types of aluminum alloys now in use, far too numerous, are being reduced to a few standards.

2. Manufacturing scrap is vigorously segregated by type. If the origin of the scrap is unknown it is necessary to test each piece and segregate it into usable types. Two rapid methods are used for pieces whose shape gives no clue to the nature of the part and its probable composition: *(a)* Spot tests, using drops of various reagents such as caustic solutions, hydrochloric and nitric acids, cadmium sulphate and others which color or react in a characteristic manner with the principal alloy families, such as Al-Cu, Al-Zn, Al-Si, Si-Mn, Al-Mg, Al-Zn-Cu and Al-Si-Cu. *(b)* The second method is useful to the skilled workman in the form of scratching points of classified hardness.

3. Establish standard compositions for secondary ingot which result from the careful fusion of segregated scrap. It is believed that about 20 such secondary alloys, each with useful commercial properties, can be formulated.

4. Devise fluxes for melting and refining the aluminum scrap. They should have a large solubility for aluminum and magnesium oxide, should not induce corrosion if traces of them remain behind entrapped in the metal, should melt in the range of 1100 to 1300° F. into fluids of low viscosity and density. Principal ingredients are alkaline fluorides and chlorides, but there is room for great improvement in French practice.

When these objects have been achieved, the melting of aluminum scrap, even though accompanied by considerable change in chemical composition, will be vastly improved, and will return to the secondary ingot many of the original qualities of the primary metal.

ALBERT M. PORTEVIN
Bessemer Medallist

*EDITOR'S NOTE — The situation is different in the United States. Magnesium can be and is being separated and recovered from the bath, and the melting is so conducted that foundry and die casting alloys of excellent characteristics are produced — or else shot aluminum suitable for steel deoxidation.

# MAGNETIC MEASUREMENT

# OF THE HARDENABILITY

# OF CARBON TOOLSTEELS

By C. B. Post
and W. H. Fenstermac[...]
Metallurgical Dept.
The Carpenter Steel Co.
Reading, Pa.

SOME TIME AGO we described★ a cone-shaped test piece for determining the hardenability of carbon toolsteels, originally designed to amplify the gradations in hardenability in the shallow hardening grades. On the basis of several years' usage in the routine testing of these types of steel in Carpenter Steel Co.'s laboratories, we can now state that the cone test is reliable and has sufficient sensitivity for the testing of shallow hardenabilities.

In the beginning, the hardened specimens were ground down to the longitudinal axial plane and Rockwell hardness readings made down the center line. (Carbon contents of the steels vary from 0.80% to 1.30%.) The distance is measured from the tip of the cone to where the hardness is C-55. Cooling velocities along the center line of the cone specimen were known from experimental measurements as noted in our previous papers, and so the cooling velocity past 1300° F. necessary to yield this Rockwell hardness of C-55 could be determined. This latter cooling velocity associated with C-55 has been called the "critical cooling velocity". Our previous reports showed the utility of this critical cooling velocity, and it is pertinent to point out that the adoption of the

cone test in our laboratories has eliminated al[...] five specialized hardenability tests used by d[...] ferent consumers. This was done by correlat[...] the customers' specialized tests and our cone [...] in terms of the more fundamental hardenabil[...] parameter "critical cooling velocity = °F./sec. p[...] 1300° F. to yield C-55 hardness".

The grinding down of these hardened c[...] was found to be expensive and time consum[...] even when done in batch lots, and means w[...] sought for eliminating this operation.

The electromagnetic equipment finally de[...] oped for eliminating the grinding of the cone[...] shown in Fig. 1 and 2. Basically, the metho[...] to magnetize the hardened cone in a const[...] magnetic field of strength H in Coil $C_1$, carr[...] 1.5 amp.). This magnetizing coil is 3½ in. l[...] and has 3600 turns of 21-g. copper wire. [...] residual magnetism in the sample causes m[...] netic flux to traverse the path of the high sili[...] laminated yoke (Y of Fig. 2), and the amoun[...] this flux is indicated by the current generate[...] the rotating constant-speed coil $C_2$ in the bac[...] the yoke.

The current is now reversed in the magne[...] ing coil $C_1$, and is gradually increased from [...] in milliampere steps, until the rotating coil [...] to generate any current in the indicating cir[...] The galvanometer G in the indicating circu[...] of the d'Arsonval type and is operated [...]

★O. V. Greene and C. B. Post, S.A.E. *Journal (Transactions)*, Vol. 49, 1941, p. 278; C. B. Post, O. V. Greene and W. H. Fenstermacher, *Transactions* ⊕, Vol. 30, December 1942, p. 1202.

*Fig. 1 — Electromagnetic Hardenability Testing Unit in Carpenter Steel Co.'s Laboratory*

shunts $S_2$ so that full sensitivity is finally obtained when the current is small enough. When the current in the indicating circuit is zero (representing zero flux in the yoke) the current is read in the magnetizing circuit by means of a milliammeter MA. This is the amount of current necessary to create a field in the magnetizing coil which is just sufficient to demagnetize the cone specimen. This reading of the milliammeter is called here the "meter reading".

This demagnetizing current (meter reading) is one of the variables specifying the coercive force of the hardened cone specimen and, in fact, the coercive force is directly proportional to this current.

Under these conditions, we are relating the coercive force of the cone specimen to the relative amounts of hardened case (martensite) and unhardened core (fine pearlite). At constant carbon content, and manganese, silicon, chromium, nickel, and other incidental elements held within the limits ordinarily associated with such shallow-hardening carbon steels (for example, 0.15 to 0.40% manganese, 0.20 to 0.40% silicon, 0.05 to 0.25% chromium, 0.10 to 0.25% nickel, 0.02 to 0.08% molybdenum, 0.020% max. phosphorus and 0.020% max. sulphur) the coercive force of hardened cone specimens of various hardenabilities can be standardized against critical cooling
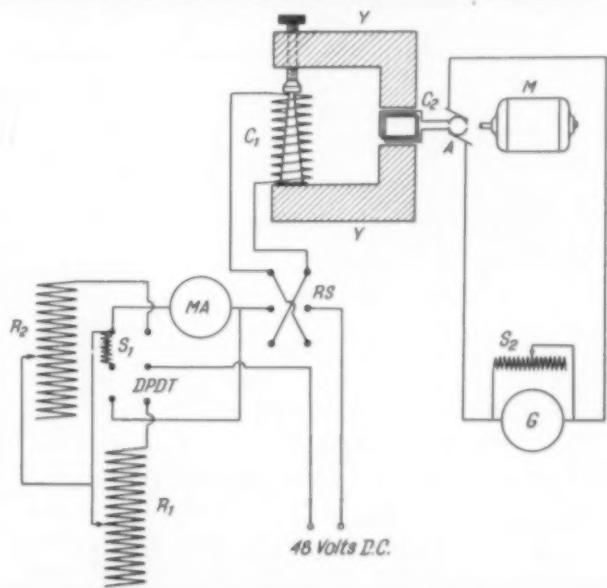


*Fig. 2 — Wiring Diagram of Hardenability Tester*

Y — Silicon-iron laminated yoke
$C_1$ — Magnetizing coil, 3000 turns, No. 21-g.
$C_2$ — Rotating coil, 500 turns, No. 30-g.
A — Armature and commutator
M — Synchronous motor, 1800 r.p.m.
RS — Reversing switch
$R_1$ — Control resistance, 27 ohms, coil $C_1$, 15 amp.
$R_2$ — Demagnetizing control resistance, 2700 ohms
MA — 0-150 MA milliammeter
$S_{1,2}$ — Shunts
G — Galvanometer
DPDT — Double pole, double throw switch
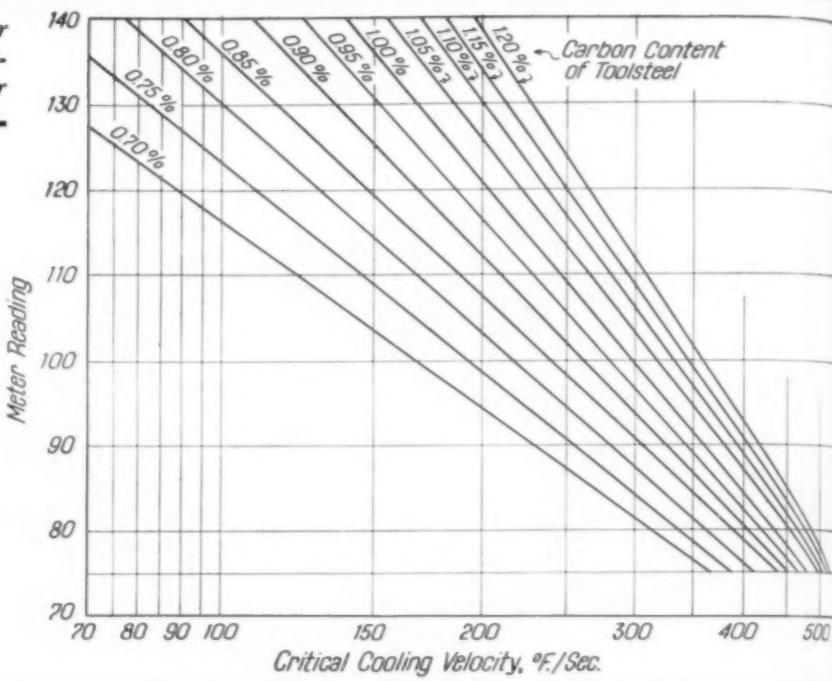
velocity. Figure 3 shows the calibration chart used with our instrument.

In making tests, the instrument shown in (Fig. 1) is checked before each batch by measuring the "meter reading" for a completely hardened cone specimen, an unhardened sample, and a standard cone of 260° F./sec. The carbon content of the sample must be known to use the calibration chart, Fig. 3 (heat analysis carbon is sufficient for this).

Periodically the entire instrument is checked by grinding down several cone specimens and comparing the critical cool-

ing velocity by the electromagnetic method and that determined by Rockwell readings down the center line of the cone. Of 159 heats checked in this manner, 70.5% showed errors in the range of 0 to ± 4%, 23.9% showed errors in the range ± 4 to ± 8%, and 5.6% showed errors in the range ± 8 to ± 10%.

To illustrate the possible utility of such an instrument to those primarily concerned with Jominy hardenability testing, a number of Jominy specimens were made with flat ends from Carpenter "Stentor", oil hardening, non-deforming toolsteel (0.90% C, 1.75% Mn) and some similar experimental analyses but shallower and deeper hardening than the narrow range to which this type is controlled. The Jominy specimens were obtained midway, surface to center, from 4-in. square billet stock, and machined to $\frac{7}{8}$-in. diameter, 3 in. long. (We used $\frac{7}{8}$-in. diameter instead of the conventional 1-in. diameter because of the size of the magnetizing coil.) A $\frac{1}{4}$-in. diameter wrought iron pin bridged the gap between upper pole of the yoke and the specimen when the specimen and coil were seated on the lower pole of the yoke. The same procedure in making the electromagnetic test was employed as in the cone test described above. After demagnetization, the "meter reading" was directly correlated against the °F./sec. past 1300° F. appropriate to C-55, as determined from Rockwell readings on two ground flat surfaces on the Jominy surface. Such a correlation is shown in Fig. 4.



Fig. 4 — Standardization of Electromagnetic Tester for Flat End Jominy Test Pieces; "Meter Reading" Vs. Critical Cooling Velocity (°F./Sec. Past 1300° F. to Yield C-55). "Stentor" type

HOW NICKEL HELPS **Maintain**

YOUR MACHINE TOOL OPERATING

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*Moore Jig Grinder with Spindle Housing of Low Expansion "Ni-Resist".*

## Minimize Thermal-Induced Error by Use of Low Expansion Alloy

# SECURE INCREASED PRODUCTION

Competitive conditions increase the value of units that provide high accuracy and output.

But accuracy and output fall sharply when temperature changes, even though slight, cause troublesome dimensional changes in castings such as spindle housings. For example, in jig borers and grinders, as much as .0003″ to .0005″ change in spindle location has been caused by expansion and contraction of housings.

Such deviations reduce output . . . imposing need for warm-up

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Thermal-induced error can be reduced to a negligible minimum with Type 6 Ni-Resist . . . . . . commonly termed "Invar Iron". Castings of this low expansion alloy, containing 36% Nickel, have proved successful even under very wide temperature changes.

We invite consultation on the use of Nickel Cast Irons and other alloys containing Nickel. Send us details of your problems for our recommendations.

### Here's what J. R. Moore* says about Type 6 Ni-Resist:

*"Since we started using 'Invar Iron' . . . we have found that we have been able to virtually eliminate the warming-up periods previously required to make accurate settings or determine accurate locations. The overall efficiency of these two machines is probably increased by at least 20% and no difficulty on this score has since been encountered by users. This is an important factor, particularly in the use of machines intended to work within tolerances of ten-thousands of an inch."*

*Production Manager and Secretary of the Moore Special Tool Company, Inc., Bridgeport, Conn.

# THE INTERNATIONAL NICKEL COMPANY, INC., 67 Wall Street, New York 5, N.Y.

# Arc-Welding Troubles and Their Cures

*Westinghouse Electric & Mfg. Co.*

## Cracked Welds

**Causes:** A—Joint too rigid. B—Welds too small for size of the parts joined. C—Poor welds. D—Improper preparation of joints. E—Improper electrode.

**Cures:** A—Design the structure and develop a welding procedure to eliminate rigid joints. B—Avoid small welds between heavy plates; increase the size of welds. C—Do not make welds in string beads; make weld full size in short sections 8 to 10 in. long. D—Use welding sequence that leaves ends free to move as long as possible. E—Ensure that welds are sound and the fusion is good. F—Preheat. G—See that joints have uniform and proper free space; sometimes free space is essential; in other cases, a shrink or press fit may be required.

## Distortion

**Causes:** A—Shrinkage of deposited metal pulls parts together and changes relative positions. B—Non-uniform heating of parts during welding distorts them before welding is finished; final welding of parts in distorted position preserves these improper dimensions. C—Improper welding sequence.

**Cures:** A—Properly clamp or tack parts. B—Pre-form parts to compensate for shrinkage of welds. C—Distribute welding to prevent excessive local heating. Preheating is especially desirable on heavy structures. D—Remove rolling or forming strains before welding. E—Develop a proper and definite welding sequence.

## Metallic Arc Blow

**Causes:** A—Magnetic fields cause the arc to blow away from the point at which it is directed. Magnetic blow is particularly noticeable with direct current at ends of joints and in corners.

**Cures:** A—Ground on the work properly in the direction the arc blows. B—Separate the ground in two or more connections. C—Weld toward the direction the arc blows. D—Hold a short arc. E—Change magnetic path around arc by steel blocks. F—Use alternating current.
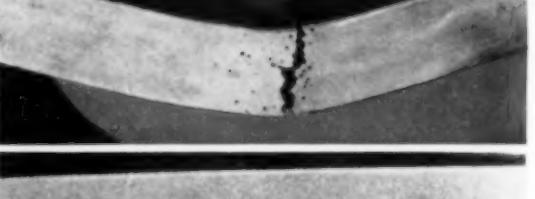
## Brittle Joints

**Causes:** A—Base metal has too high a degree of hardenability. B—Improper preheating. C—Unsatisfactory electrode.

**Cures:** A—If heat-affected zone becomes hard as a result of rapid cooling, preheat at 300 to 500° F. before welding. B—Multiple layer welds will tend to anneal hard zones. C—Annealing at 1100 to 1200° F. after welding generally softens hard areas formed during welding. D—The use of austenitic electrodes is sometimes desirable on steels which harden readily. The increased weld ductility compensates for the brittle heat-affected area in base metal.

## Undercut

**Causes:** A—Excessive welding current. B—Improper manipulation of electrode. C—Attempting to weld in a position for which the electrode is not designed.

**Cures:** A—Use a moderate welding current and do not try to travel too rapidly. B—Do not use too large an electrode; if the puddle of molten metal becomes too large, undercut may result. C—Avoid excessive weaving, which will cause undercut; a uniform weave will aid greatly in butt welds. D—If an electrode is held too near the vertical plane when making a horizontal fillet weld, the vertical plate may undercut.

## Irregular Weld Quality

**Causes:** A—Improper electrode manipulation. B—Excessive welding current. C—Welding in improper position for which electrode is designed. D—Improper joint design.

**Cures:** A—Use a uniform weave or rate of travel at all times. B—Avoid excessive welding currents. C—Use an electrode designed for the position and type of weld. D—Prepare joint properly.

## Welding Stresses

**Causes:** A—Dangerous stresses will be induced by joints too rigid, or B—by improper welding sequence. C—Welding stresses are inherent in all welds. The illustration shows cracks in mill scale or whitewash, caused by creep of ductile metal underneath. Heavy stresses are especially likely in heavy parts.

**Cures:** A—Slight movement of parts (either mechanical or by differential preheating) during welding will reduce intensity of welding stresses. B—Make the weld in as few passes as practical. C—Peen each deposit of weld metal. D—Anneal finished product at 1100 to 1200° F.; heat very slowly and soak 1 hr. per in. of thickest metal. E—Develop a procedure that permits all parts to be free to move as long as possible.

# ENEMY MATÉRIEL

## from the

# METALLURGICAL POINT OF VIEW

Report to War Metallurgy Committee

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WHEN ENEMY ORDNANCE is captured in usable condition, the best use for it is to turn it immediately against the enemy to hoist him with his own petard. At Aberdeen Proving Ground, where enemy arms are collected, officers and men have been familiarized with the design and operation of enemy guns, and these experts, scattered through the forces in the field, are prepared to instruct the field forces just how to operate captured guns. They also collect, examine in the field, and forward for more detailed examination, samples of new design, or those of old design but late manufacture.

Next in order is the study of captured matériel as to its capabilities and limitations, so that proper defense can be opposed to it and so that any useful kinks in design, methods of manufacture, or materials used, that might be applicable to improving quality or increasing production of our own weapons, may be promptly noted and utilized.

This involves experimental determination of how the matériel actually functions, the accuracy of guns, the penetration power of projectiles, the resistance of armor, the speed of tanks, the life of their treads, and all such questions bearing on actual battle efficiency. Much of this is done at the Aberdeen Proving Ground, with specialized attention at Watertown, Frankford, Picatinny and Rock Island Arsenals. The aid of civilian experts among producers is regularly enlisted.

Not only arms and ammunition, but tanks, trucks, fuels, lubricants,[23] paints, and similar materials are scrutinized. (See Note *a*, page 290.)

The Navy has analogous problems and handles them in a rather similar fashion, although collection of matériel for examination is more difficult, for instead of being abandoned by a retreating enemy to be picked up from the ground at leisure, enemy ships are generally sent to Davy Jones, who doesn't send in specimens. The Navy, however, does manage to collect a lot of Japanese naval aircraft.

Our British Allies have the same problems and deal with them in much the same fashion; both service and civilian experts examine and appraise captured matériel. Reports are exchanged between the two countries. The Germans likewise pay attention to the British and American arms that fall into their hands and have published descriptions of the design and materials used in captured aircraft engines and ordnance matériel.

**Economic and Technical Aspects** — In all of these studies the engineering aspect is not the only one of interest. An enemy shift from one raw material to another, or from one method of production to another, may be very revealing as to his shortages in materials or production equipment, and these show up those bottlenecks whose further restriction by military or economic action will hurt him most.

Hence, the Foreign Economic Administra-

tion, as well as the Army and Navy, has a keen interest in enemy steps in conservation and substitution. Observations of what expedients our enemies are adopting may serve as useful corroboration of the bits of information gathered by the various Intelligence Services.

Naturally, the captured material is immediately and intensively studied by the armed Services from the functional standpoint, and is not released for examination as to materials and fabrication methods until it has fully served that prior purpose. Unless plenty of duplicates of anything new and interesting have been captured, there is a delay between its capture and its release to materials engineers for study. Any items of immediate interest and importance as to materials used are studied by the appropriate Service (and civilian) experts the moment they can be released for such study. See NOTE (b).

There are distinct limitations to the validity of even tentative conclusions drawn from careful study of enemy ordnance. One may be very certain of the composition of a piece of metal, of its properties, and quite certain as to methods of manufacture and fabrication, but quite uncertain as to how representative that piece may be of regular enemy practice. Only when there are available a considerable number of like parts whose dates of manufacture are known, can a consistent picture of regular practice be shown and a reasonable guess made as to the reasons underlying a change in practice. For example, when a Jap gun part is found which contains

0.60% carbon and 0.16% phosphorus, and with corresponding brittleness, it does not mean that this metal is generally used. It might mean poor metallurgical control, or it might mean that the Jap was trying to make a free machining steel.

Evaluation of trends on the basis of a few grab samples is not very reliable, but even though nothing more than intelligent guesses can be made in a good many cases, yet — as the bits of evidence accumulate, and especially when the findings are supplemented and corroborated by the examinations made by the British — some trends do become rather clearly established. [See NOTE (c) for information on the selection of specimens.]

Metallurgical practice tends to be quite similar throughout all industrialized countries, so it is not surprising that the verdict after examination is usually that "conventional materials have been used". It is the deviations from conventional practice that are being sought. Hence, many of the examinations that have had to be made from the point of view of completeness merely supply a background for general appraisal rather than anything of particular interest in themselves.

We shall not attempt to go into detail here, but merely to present a few general impressions of over-all trends that appear to have been established. Most of these points are likewise verified from general economic knowledge and specific information from the Intelligence Services, to which they add corroboration.

NOTE (a) — General Barnes[1] and Colonel Ritchie[2] in the publications so noted in the Bibliography, page 320, have outlined the work of the Ordnance Department Research and Development Service along these lines. Analogous examinations of rations, clothing, and supplies are made by the Quartermaster Corps, while the Army Air Forces do the same sort of thing with aircraft.

Similarly, the Office of Scientific Research and Development, through its agency the National Defense Research Committee, has sponsored extensive research on metallurgical problems. This has been done by means of about 100 contracts with various industrial and educational laboratories. These contracts are under the direct supervision of the National Defense Research Committee's Division 18 on War Metallurgy.

(The Office of Scientific Research and Development was established June 28, 1941, by Executive Order 8807 to "serve as the center for the mobilization of the scientific personnel and resources of the Nation in order to assure maximum utilization of such personnel and resources in developing and applying the results of scientific research to defense purposes". The organization, through its director, Vannevar Bush, has accomplished this objective primarily through the medium of contracts with educational institutions and industrial organizations for the services of their scientists and the use of their laboratories. The work on metallurgical problems at Battelle Memorial Institute was sponsored, in the main, by the Office of Scientific Research and Development under one of these contracts.)

NOTE (b) — Since the Service's facilities are often overcrowded, civilian help is required to amass much information and evidence to supplement and strengthen the conclusions as to economic trends, and for further scrutiny to make more certain that nothing of engineering importance has been overlooked. Since so great a proportion of all munitions is made up of metals, this involves considerable metallurgical work.

Much of this metallurgical work has been done by the Office of Scientific Research and Development through a contract with the National Academy of Sciences. Under this contract, the National Academy of Sciences has made available the services of its various committees and facilities, prominent among which is the National Research Council. Under the latter organization there has been formulated the War Metallurgy Committee. Colonel Ritchie, assistant chief, Research and Development Service of the Ordnance Department, called upon it for "active assistance in examina-

## German Shortages

It is generally considered that Germany is cramped for the following metals, in about this order: Copper, nickel, molybdenum, vanadium, tungsten, chromium and manganese. Indeed, about ten years ago, *devisen* regulations were set up in Germany to encourage, through the pocket-book, the development of alternates for imported materials such as oils, metals, and alloys, and the technical literature began to offer suggestions for substitutions,[3,4] especially for nickel.

It is of particular interest to appraise the German scrap situation, as evidenced by the residual metals in standard compositions, in order to figure out whether they are likely to be able to resort to the expedient that has been so useful in the United States — that is, of utilizing the hardenability-conferring elements (nickel, chromium and molybdenum) present in scrap. The high level of these elements in much of our scrap has made the so-called triple-alloy or NE steels available without having to draw heavily on the supplies of new alloying elements, as would have been necessary to produce the old S.A.E. alloy steels, for which the NE steels are proving so widely applicable as substitutes.

**Steel for Copper** — Copper has long been critically short in supply in Germany. A good proof that even a small amount of copper is worth saving is shown by the German duralumin type of aluminum alloys in which somewhere around 4% of copper occur as an alloying element. They carefully control the copper content right at the low end of the accepted range. (Dreyer and Hansen[5] have published the results of many experiments on this topic.) This control saves perhaps one-quarter to one-half per cent copper that would otherwise have been used to meet pre-war specifications.

The tight German copper situation is evidenced by the early substitution (around 1934) of deep-drawn steel for brass in the larger cartridge cases of fixed ammunition, and the shift in the protective coatings for the steel cases from copper cladding, through an electrolytic coating consisting of a copper strike, topped by a thin layer of brass, and finally abandoning these for a mere lacquer coating. It is likewise evidenced by the shift in driving bands from all-copper, through a duplex band made of copper and soft iron, finally to an all-iron band made by powder metallurgy.

Typical steel cartridge cases, such as that in Fig. 1, have the compositions shown in Table I.

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...tion of such captured material as may be desirable, with special emphasis on the strategic aspect, to uncover hidden processes of manufacture which may be helpful to our industry, to disclose changes in manufacturing procedures, bottlenecks, and shortages in enemy industry". This work of the War Metallurgy Committee on the examination of enemy matériel has been under the supervision of C. R. Maxon, to whom grateful acknowledgment is made.

In analogous fashion, the Army Air Forces examines captured aircraft, first from the functional and design point of view, and second from that of materials. This examination of metals used in enemy aircraft is supplemented, when the facilities at Wright Field and elsewhere are crowded, by studies by the War Metallurgy Committee's group. Wright Field personnel help select those specimens the examination of which

might produce useful information. For the Navy, different groups pass on the selection and the work is cleared through the Coordinator of Research and Development. The advice of the Naval Aircraft Factory is particularly helpful in selecting the vital and interesting parts of aircraft and engines.

While any metal used by the enemy in any application may be presented for study, and the Foreign Economic Administration selects various miscellaneous objects of interest, most of the metallurgical information obtained relates to ordnance of one sort or another, and to aircraft.

Colonel Ritchie has suggested that a general survey of enemy matériel from the metallurgical point of view might be assembled from the bits and pieces of information so far available. This article is an attempt to carry out his suggestions, and reflects the work done under the sponsorship of the

Office of Scientific Research and Development in this field.

NOTE *(c)* — The examinations have to be limited, lest they become foolishly exhaustive without being illuminating, yet must be complete enough to minimize the chances of missing important information. A machine gun may have hundreds of parts, an airplane engine thousands, but not all of them are necessarily informative. As the War Metallurgy Committee project on Enemy Matériel is set up, the specimens for examination are selected by special groups of experts. The Services, of course, automatically send in anything of particular interest or that needs very early attention. To get a suitable chronological series, the various receiving depots or dumps are visited periodically by "Selection Subcommittees" made up of representatives of the Services most concerned, of the Foreign Eco-

## Table I — Chemical Analyses of Steel in German Cartridge Cases

| Date | Use | C | P | S | Mn | Si | Ni | Cr | Mo | Cu | Sn | Al | Ti |
|------|-----|---|---|---|----|----|----|----|----|----|----|----|----|
| 1940 | 50-mm. H.E. | 0.07 | 0.013 | 0.022 | 0.29 | 0.12 | 0.03 | <0.03 | tr. | 0.07 | tr. | 0.05 | — |
| 1940 | 50-mm. A.P., H.E. | 0.12 | 0.008 | 0.024 | 0.35 | 0.10 | 0.04 | <0.03 | tr. | 0.15 | tr. | 0.05 | — |
| 1941 | 50-mm. H.E. | 0.13 | 0.014 | 0.033 | 0.24 | 0.10 | 0.06 | <0.03 | tr. | 0.15 | 0.01 | 0.07 | — |
| 1941 | 50-mm. A.P., H.E. | 0.10 | 0.020 | 0.047 | 0.27 | 0.08 | 0.09 | 0.04 | 0.01 | 0.15 | 0.01 | 0.04 | — |
| 1942 | 50-mm. H.E. | 0.09 | 0.020 | 0.046 | 0.42 | 0.12 | 0.09 | 0.05 | 0.01 | 0.17 | 0.02 | 0.03 | — |
| 1941 | 20-mm. H.E. | 0.35 | 0.02 | 0.02 | 0.40 | 0.12 | 0.06 | <0.03 | tr. | 0.18 | tr. | 0.02 | 0.03 |
| 1941 | 20-mm. H.E. | 0.26 | 0.02 | 0.03 | 0.44 | 0.12 | 0.07 | 0.04 | tr. | 0.13 | 0.01 | 0.07 | 0.04 |
| 1941 | 20-mm. H.E. | 0.20 | 0.01 | 0.03 | 0.40 | 0.11 | 0.06 | 0.03 | tr. | 0.17 | 0.03 | 0.02 | 0.03 |
| 1942 | 20-mm. H.E. | 0.29 | 0.02 | 0.02 | 0.29 | 0.05 | 0.05 | <0.03 | tr. | 0.09 | 0.01 | 0.03 | 0.03 |
| 1942 | 20-mm. H.E. | 0.24 | 0.02 | 0.03 | 0.44 | 0.14 | 0.04 | 0.04 | tr. | 0.11 | tr. | 0.03 | 0.03 |
| 1942 | 20-mm. H.E. | 0.26 | 0.02 | 0.03 | 0.54 | 0.24 | 0.06 | 0.07 | 0.01 | 0.19 | 0.02 | 0.01 | 0.02 |

nomic Administration, and of the direct workers on the War Metallurgy Committee project. These committees advise those in charge as to the parts performing the most vital functions or otherwise most likely to give the most information for the effort expended.

In the examination of the selected specimens, minor parts are looked over for methods of manufacture, spark tested to indicate whether they are of alloy steel, and examined further if they seem of interest. More vital parts and large parts are subjected to spectrographic analysis and such chemical analyses as may be warranted, tested for hardness, and subjected to mechanical tests, where size permits and the importance warrants. Macro-etching and metallography reveal much as to the method of manufacture and the heat treatment.

Examinations are made wherever metallurgists of suitable background and having suitable equipment are available. The work is centered at Battelle Memorial Institute as a control point to which material is sent by the several governmental agencies and Army and Navy laboratories for analysis and appraisal. All reports are also cleared through the group at Battelle and the bulk of the actual examinations is carried out there. Much work is farmed out to industrial laboratories (such as those of the firms and groups with which various engineers on the War Metallurgy Committee are connected in their regular capacities), and university and institutional laboratories, the effort being to get specially expert help in each particular case. The hearty cooperation of these laboratories has considerably eased the task.



Fig. 1 — Typical German 50-Mm. Cartridge Case, Made of Steel, and Its Primer Plug

These steel cases show proper variation of hardness and structure from base to mouth, the deep drawing and annealing processes having been carefully done. The steel is heavily aluminum treated, and the low residuals show that so-called "carbon steel" scrap, though doubtless specially selected for the purpose, had a low level of residuals.

The 20-mm. high explosive cases of a series ranging from 1935 to 1942 manufacture were of brass. The fuzes were brass and the projectiles had copper rotating bands. In one 1941 shell the steel case appeared, but a steel fuze and copper rotating band were used; in another, an aluminum fuze and a powder iron band were used. In 1942 this last combination persisted. The late steel cases were lacquered, not brass plated.

The steel in these 20-mm. cases analyzed according to the last six lines of Table I. It will be observed that these are like the 50 mm., but of higher carbon. The coatings of these particular 20-mm. cases consisted of a copper strike (0.0001 in.) covered by 0.0002 to 0.0006 in. of brass, replacing a brief earlier use of copper-clad steel, in which the copper amounted to about

one-tenth of the wall thickness. The brass plate is porous and of very little value for corrosion protection, although it may have been designed to have a psychological value in making the men in the field think they had brass cases — but they must have soon known better.



*Fig. 2 — Cross Section Through Duplex Driving Band on German Projectile. Full size. Lower portion is body of projectile; it contains a knurled and undercut groove into which is cold rolled a ring made of bi-metal strip — soft steel inside, copper outside*

At present the brass coating is usually left off and replaced by lacquer. At one stage a phosphate treatment was applied before lacquering, but lately good adhesion of lacquer is secured without it. The shift not only saves copper, but avoids some steps in processing.★

portion is aluminum-treated soft steel, very like that used in the cartridge cases, but with lower carbon (about 0.06%), lower manganese (about 0.15%), and lower silicon (about 0.03%). The band is made as a strip, not a ring, and to hold the band in place, in spite of there being a joint

**Table II — Analysis and Hardness (Vickers Brinell) of Driving Bands Made of Iron Powder**

| Date | Use | C | P | S | Mn | Si | Ni | Cr | Mo | Cu | Sn | Al | Ti | Hardness |
|------|-----|---|---|---|----|----|----|----|----|----|----|----|----|----------|
| 1940 | 50-mm. H.E. | 0.07 | — | 0.03 | 0.37 | 0.05 | 0.05 | 0.03 | 0.01 | 0.12 | 0.03 | 0.02 | 0.01 | 58 |
| 1940 | 50-mm. A.P., H.E. | 0.05 | 0.02 | 0.02 | 0.29 | — | 0.04 | 0.03 | — | — | — | — | — | 56 |
| 1941 | 50-mm. A.P., H.E. | 0.08 | 0.02 | 0.025 | 0.30 | — | 0.06 | 0.03 | — | 0.32 | — | — | — | 61 |
| 1942 | 50-mm. A.P., H.E. | 0.07 | 0.01 | 0.02 | 0.06 | 0.20 | 0.04 | <0.03 | tr. | 0.03 | tr. | 0.04 | 0.02 | 57 |
| 1941 | 50-mm. H.E. | 0.09 | 0.02 | 0.025 | 0.32 | — | 0.06 | 0.03 | — | — | — | — | — | 61 |
| 1942 | 50-mm. H.E. | 0.07 | 0.01 | 0.02 | 0.29 | 0.12 | 0.03 | <0.03 | tr. | 0.07 | 0.005 | 0.05 | tr. | 62 |

**Iron Driving Bands** — The driving bands on projectiles, originally copper, went through a transition stage in which a duplex band was used, with soft iron in the groove and copper extending above the surface of the projectile. In this way the part of the band that engages the lands or rifling, and is engraved, is all copper, so the gun shouldn't know any difference. The soft "iron"

in it, the groove is heavily knurled and undercut as shown in Fig. 2. The banding is a nice job, the joint is not evident to the eye and the bands hold on quite as well as the all-copper ring. The iron part is appreciably cold worked by the banding operation.

Considerable extra effort, in making the duplex strip, in cutting it to very exact length, and in altering the banding technique, was expended in order to save half the copper that would have been used otherwise.

There was a will to save *all* the copper, not merely half of it; so that final step was to a sintered band of powder iron. A pair of such bands in place on a shell is shown in



*Fig. 3 — Section of German Projectile Having Two Driving Bands Pressed of Iron Powder, Sintered, and Cold Rolled Into Place*

★EDITOR'S NOTE — A more complete description of the metal in German steel cartridge cases will be published in the next issue of *Metal Progress*.

Fig. 3. In order to give room for the displaced metal to flow, the shell is relieved slightly just above the band. The knurling and the undercut are much the same as with the duplex band, but the band is made as a ring since it would not stand forming up from strip. Composition of typical iron powder bands are in Table II.

Some observers have termed the powder used in making the bands "electrolytic iron", but it is obviously derived from the same sort of steel used in the cartridge cases. One would ordinarily expect that mill scale (or thin scrap intentionally oxidized to the equivalent of mill scale) would be used because of the ease of grinding it to fine powder, the oxide then being reduced by hydrogen in the usual way. This may be what is done, but it seems equally possible that very fine chips of the cartridge case steel are collected, sized, pressed and sintered, thus being used direct without the work of converting the steel to a pulverulent oxide and reducing it back to metal.

The band has a variable amount of voids, usually about 20%, and this porosity makes the apparent hardness lower than the actual hardness of the iron particles. To prevent the corrosion that would otherwise be met, the voids that reach the surface are filled with paraffin, usually less than 2% by weight. The band is pressed and only lightly sintered, just enough to make it hold together in seating the band. Once the band is in place it withstands the compressive and shear stresses of service, but when pried off with a chisel it breaks into several pieces.

Most engineers and metallurgists would turn thumbs down on such a material for such use on the score of brittleness, but the Germans are not worried by properties that look bad but do not prevent satisfactory service. Much hesitation in the adoption of such a band might also be expected through fear of barrel wear, from rubbing iron against steel. No data are at hand on whether the band causes increased barrel wear or not; if it does, the Germans put up with it in order to conserve copper.

Nickel has long been in very short supply in Germany. Projectiles of the type that are quenched and tempered, and armor made in 1937-1939 were more or less regularly of the 3½ Ni, ¾ Cr, ½ Mo type, but a strong movement toward omitting the nickel and raising the chromium had been carried on for a long time before that. Pomp and Hempel[6] presented arguments and much experimental evidence in 1937 for replacing nickel with other alloying elements.

Houdremont[7] (of Krupp) described the practice of one alloy steel works in Germany from which it appears that in 1931-32 (a period of low production of one steel used for carburizing and heat treatment) two out of four (unstated) units were of Ni and Ni-Cr steels taken together, and the other two of *sparstoffarmen Cr-Mo Stahl*, whereas in 1935-36 the production was 55 units of which eight were Ni and Ni-Cr steels and the Cr-Mo steels. Concurrently, the average nickel content fell from 2.3% in 1929-30 to 0.5% in 1935-36. He also comments on lowering tungsten and raising molybdenum and vanadium in high speed steel, as though the latter two were expected to be more obtainable.

Italy was developing a similar point of view. Masi[8] in 1939 discussed manganese, chromium-manganese, and chromium-molybdenum steels as acceptable substitutes for those with less available alloying elements.

For ten years German metallurgists have been determining the properties and working out the technique of handling these steels. Their widespread use in Germany is evidenced by such articles as that by Balster and Eilender[9] who discuss manganese-chromium steels, with or without molybdenum, vanadium and extra silicon in heat treatable steels for service in heavy truck engines.

An example which brings out the low level of residual nickel in the scrap used in making the chromium steels is the 2-in. diameter torsion bars used in the suspension of the PzKpfw III tank. This steel, quenched and tempered to a Brinell range of 400 to 500 on the outside of the bar, contained 0.50 to 0.60% C, 0.20 to 0.30% Si, 0.65 to 0.90% Mn, 0.65 to 1.20% Cr, none to 0.25% Ni, none to 0.20% Mo, 0.10 to 0.20% V, and about 0.10% Cu — that is, it was essentially a chromium-vanadium steel. When the nickel and molybdenum were at appreciable levels, the chromium tended toward the lower end of the range.

## German Armor

Early aircraft armor sometimes contained nickel. It was reported by Staffartde[10] that the thin armor on Dornier was of the two following compositions:

| | DORNIER | | MESSER- |
| | SAMPLE A | SAMPLE B | SCHMIDT 109 |
|---|---|---|---|
| C | 0.30% | 0.49% | 0.46% |
| Si | 1.33 | 0.96 | 0.60 |
| Ni | 1.13 | .... | .... |
| Cr | 1.08 | 1.49 | 1.35 |
| Mo | .... | 0.23 | 0.55 |

Later German armor, whatever its thickness, and whether it is homogeneous, flame-hardened or carburized, consistently relies on chromium and molybdenum as the main alloying elements. For example, Ritchie[11] cites tank armor compositions as shown at the top of the next column.

**German Tank Armor**

| | TIGER | PzKPFW III |
|---|---|---|
| Carbon | 0.50% | 0.44% |
| Silicon | .... | 0.25 |
| Nickel | .... | tr. |
| Chromium | 2.50 | 1.30 |
| Molybdenum | 0.60 | 0.50 |
| Vanadium | .... | 0.17 |
| Copper | .... | 0.18 |

Ritchie also comments on the late use of two thin face-hardened plates separated 4 to 6 in. by spacers, instead of one thick plate. Laminated armor is not liked by many authorities as well as a single, thick plate, although there are data to indicate that, while not giving the advantage expected by some theorists, it comes pretty close to acting as well as a single plate, other things being equal. But, in order to make other things equal, a thick single plate must be hardened *through*, and to secure through-hardening in heavy plate, alloys have to be piled in — whereas

quenching cannot be avoided, even when the steel contains lots of alloy.

In most German armor the chromium may run from 1 to $2\frac{1}{2}$%, the molybdenum from $\frac{1}{2}$ to nearly $\frac{3}{4}$%, but the common figure is 1.5% Cr, 0.25 to 0.50% Mo. When the chromium is down to 1%, silicon may be boosted to 1% or above, but more commonly the manganese is raised to 1% or above. If vanadium is used it is generally at about 0.20%, but it may be absent. Molybdenum is almost invariably present in much more than residual amounts. Nickel is present only as residual from scrap. In a few cases it may run 0.25 or even 0.40%, but in many more it hovers around 0.15%, and often only a mere trace is present.

In the normal, world-wide condition as to residuals in alloy scrap one would expect to find, even in the chromium-molybdenum armor, nickel at the levels in the analyses of Czech tank armor

**Table III — Analyses of Czech and German Tank Armor**

| ARMOR | C | P | S | MN | SI | NI | CR | MO | V | CU | SN | AL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Czech ⅝-in. | 0.42 | 0.012 | 0.011 | 0.98 | 1.10 | 0.25 | 1.12 | 0.04 | 0.03 | 0.17 | 0.02 | 0.005 |
| Czech ⅝-in. | 0.45 | 0.017 | 0.010 | 0.99 | 1.10 | 0.37 | 1.20 | 0.08 | 0.04 | 0.25 | 0.04 | 0.01 |
| Czech 2-in. | 0.49 | 0.012 | 0.023 | 0.74 | 0.43 | 0.55 | 1.52 | 0.31 | tr. | 0.18 | 0.04 | 0.01 |
| Czech 2-in. | 0.50 | 0.007 | 0.013 | 1.20 | 0.54 | 0.27 | 1.63 | 0.30 | 0.07 | 0.22 | 0.04 | 0.01 |
| German flame-hardened, 32-mm. | 0.50 | 0.007 | 0.020 | 0.66 | 0.25 | 0.14 | 1.51 | 0.58 | 0.20 | 0.12 | 0.04 | 0.02 |
| German 17-mm.★ | 0.51 | 0.011 | 0.019 | 0.64 | 0.25 | 0.11 | 1.43 | 0.61 | 0.20 | 0.07 | 0.02 | 0.02 |
| German 1¼-in. | 0.48 | — | 0.010 | 1.06 | 0.48 | 0.06 | 0.77 | 0.33 | 0.20 | 0.12 | — | 0.01 |

★From PzKwIII.

thinner plate requires much less alloy for hardenability. From the point of view of alloy conservation, it makes sense to use a pack of relatively thin plates of low alloy steel rather than a single heavy plate, but it would be quite a trick to avoid warpage during heat treatment, so that a neat pack can be made.

In view of the doubtful value of mere spacing of the plates, it seems likely that the real German purpose in using two plates separated by spacers was to save alloy by avoiding a single heavy plate. The stunt of limiting the plate thickness to that which avoids slack-quenching of a steel with a limited amount of alloy, and using more than one such plate instead of a single thick one, looks to be good conservation-engineering, and worthy of emulation when alloys need saving, or when the armor gets so thick that slack-

listed in the first four lines of Table III. However, the German armor, as shown in the remainder of Table III, runs consistently lower in nickel.

The low carbon weld metal on this tank contained 2% Ni, $1\frac{1}{4}$% Cr, 0.9% W. The weld was very poor, but the German design does not rely on the welding to hold the plates together, the weld being more for sealing than for strength.

According to a Watertown Arsenal report, the $1\frac{1}{2}$-in. plates from a PzKw IV tank showed 0.40% C, 0.30 to 0.60% Ni, 2.5% Cr, 0.17% Mo, 0.02% Al, no V, and 0.0015% B. The molybdenum has been decreased from that found in earlier samples. The boron figure may mean that the Germans are playing with "needling" ("intensifiers" or "reaction alloys"), although there was no need for it in this instance as the steel has ample hardenability for the section without it.

However, analysis for boron in such small amounts is difficult and one hardly knows just how much faith to put in the analytical data unless very special precautions are taken to verify the figures.

## German Projectiles

There are many types, sizes, and designs of shells and projectiles. In some of them the properties are not very important, so they may not even be heat treated and require only carbon steel. Others have very special requirements for deep hardening properties and are given very careful heat treatment. In the carbon steel type the residual nickel and other elements making for hardenability run very low, as though scrap were very carefully segregated and all the alloy scrap worked back only into other alloy steel charges. Some of the steels used in as-forged or normalized condition analyzed as shown in Table IV.

While plenty of scrap was used (as shown by the copper and tin residuals) nickel does not go above 0.10% except in the first 20-mm. shell of 1941 listed, in which the chromium is almost as high as the nickel. The 1936 37-mm. H.E. projectile probably had an intentional addition of molybdenum. The high manganese steels used in 1937-39 have been reduced to 0.55 to 0.65% Mn in the later years. On the whole, residual alloys that make for hardenability are low in these plain carbon steels.

One would expect, with the obviously careful segregation of the carbon steel scrap from the alloy steel scrap, that when hardenability is sought the composition might indicate use of the residuals to help secure hardenability.

**Armor-Piercing Shell** — A projectile in which hardenability is necessary and to which very careful heat treatment is applied is the armor-piercing type. This projectile has a mild steel sheet wind-shield, spot welded to a "penetrating cap", which in turn is soldered to a projectile body that is very hard at the nose and much softer at the base.

On oblique impact, the penetrating cap is supposed to break through the hardened zone on face-hardened armor before the cap cracks up and flies out of the way. The hard, sharp, nose of the projectile proper digs further into the armor before it in turn cracks up. The tougher body and base of the projectile should stay together and act as a flat-nosed punch. If the body spalled off so as still to be conical, it would be more likely to slide off than to penetrate. To increase the probability of spalling on a more or less straight line, the Germans have welded a high carbon tip to a lower carbon base.

A hardness survey of a one-piece projectile and its penetrating cap is shown in Fig. 4 and a duplex welded one in Fig. 5. (For the latter, see also Fig. 6.) The way the two tend to crack up is shown by the grinding and etching cracks developed in sectioning and etching them. The projectile bodies are probably uniformly quenched and differentially tempered (base drawn at high temperature, with the temperature tapering toward the tip). To avoid quenching cracks the hardenability of tip and base should be closely the same, and the weld must be perfect.

The introduction of the welded armor-pierc-

Table IV — Chemical Analyses of German Projectiles of Carbon Steel, Not Heat Treated

| Year | Type | C | P | S | Mn | Si | Ni | Cr | Mo | Cu | Sn |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1940 | 15-cm. Anti-concrete projectile body | 0.59 | 0.025 | 0.024 | 0.83 | 0.30 | 0.04 | 0.09 | 0.02 | 0.18 | 0.02 |
| 1939 | 15-cm. projectile body | 0.67 | 0.022 | 0.034 | 1.05 | 0.36 | 0.08 | 0.03 | tr. | 0.24 | 0.05 |
| 1936 | 37-mm. H.E. projectile body | 0.44 | — | — | 0.60 | 0.23 | 0.09 | 0.09 | 0.17 | 0.15 | 0.03 |
| 1940 | 37-mm. H.E. projectile body | 0.44 | — | — | 0.64 | 0.22 | 0.10 | 0.09 | tr. | 0.13 | 0.02 |
| 1940 | 50-mm. H.E. projectile body | 0.66 | — | — | 0.65 | 0.11 | 0.04 | 0.05 | tr. | 0.17 | 0.01 |
| 1940 | 50-mm. H.E. projectile body | 0.60 | 0.03 | 0.02 | 0.69 | 0.24 | 0.05 | 0.09 | 0.01 | 0.19 | 0.01 |
| 1942 | 50-mm. H.E. projectile body | 0.72 | 0.07 | 0.03 | 0.47 | 0.38 | 0.04 | 0.11 | tr. | 0.05 | 0.01 |
| 1942 | 50-mm. H.E. projectile body | 0.75 | 0.07 | 0.045 | 0.78 | 0.38 | 0.05 | tr. | tr. | 0.05 | tr. |
| ? | 8.8-cm. H.E. shell body | 0.67 | 0.046 | 0.039 | 0.52 | 0.36 | 0.05 | 0.03 | tr. | 0.03 | tr. |
| 1938 | 75-mm. H.E., hollow charge | 0.74 | 0.09 | 0.088 | 0.59 | 0.33 | 0.05 | 0.02 | tr. | 0.06 | 0.01 |
| 1935 | 20-mm. H.E. projectile | 0.45 | 0.02 | 0.14 | 0.73 | 0.35 | 0.05 | 0.12 | tr. | 0.12 | 0.04 |
| 1937 | 20-mm. H.E. projectile | 0.52 | 0.015 | 0.03 | 0.56 | 0.26 | 0.03 | 0.03 | tr. | 0.18 | 0.015 |
| 1937 | 20-mm. H.E. projectile | 0.55 | 0.023 | 0.028 | 1.10 | 0.37 | 0.10 | 0.05 | tr. | 0.13 | 0.01 |
| 1939 | 20-mm. H.E. projectile | 0.62 | 0.015 | 0.029 | 1.04 | 0.43 | 0.08 | 0.04 | 0.01 | 0.20 | 0.01 |
| 1941 | 20-mm. H.E. projectile | 0.59 | 0.076 | 0.047 | 0.57 | 0.30 | 0.23 | 0.19 | 0.04 | 0.23 | 0.06 |
| 1941 | 20-mm. H.E. projectile | 0.63 | 0.05 | 0.028 | 0.38 | 0.12 | 0.06 | 0.07 | tr. | 0.17 | 0.03 |
| 1942 | 20-mm. H.E. projectile | 0.50 | 0.06 | 0.04 | 0.65 | 0.32 | 0.09 | 0.09 | tr. | 0.17 | 0.025 |
| 1942 | 20-mm. H.E. projectile | 0.65 | 0.04 | 0.04 | 0.60 | 0.30 | 0.09 | 0.05 | tr. | 0.18 | 0.06 |
| 1942 | 20-mm. H.E. projectile | 0.51 | 0.022 | 0.052 | 0.55 | 0.23 | 0.06 | 0.09 | 0.01 | 0.17 | 0.04 |

ing projectile illustrates the length to which the Germans will go to achieve a desired result. It seems to be a question in the minds of American ordnance experts whether the welded projectile has a real advantage over a solid one of proper hardenability, with proper differential heat treatment, but the Germans do think it has an advantage. This welding job is no easy matter; the forged tip would have to be held in a special electrode fixture, the rolled base in another, with special precautions to get good electrical contact for the very high amperage required. The butt-welding equipment, to apply the pressure and generate the power needed to make the weld, would be decidedly expensive. Such equipment has been made available for the various sizes of projectile to allow this fussy extra step in production. Macro-etched sections of this type of projectile are shown in Fig. 6, page 299.

A beautiful welding job has been done on the projectiles that are put in service. Anything less than a perfect weld might well cause cracking during quenching.

The chronology of this class of projectiles is interesting. Back in the era of copper driving bands, some of the unwelded projectiles and their penetrative caps were of steel containing around 0.40% C, 3½ to 4% Ni, 1% Cr and anywhere from 0.05 to 0.55% Mo, while others were high chromium steel (1% C, 1½% Cr, with only traces of nickel). Then the projectile, in the era of duplex driving bands, had about 0.60% carbon, 0.80% silicon, 0.90% manganese, 1 to 1½% chromium, 0.30 to 0.50% nickel and only small amounts of molybdenum (the last two residual).



Fig. 5 — Hardness Survey Across Diameter of German 75-Mm. Armor Piercing, Capped Projectile, FMAM-289, Projectile Body Itself Being Welded of Two Pieces, a Forged Tip and a Rolled Bar Base. Cap has been flame hardened
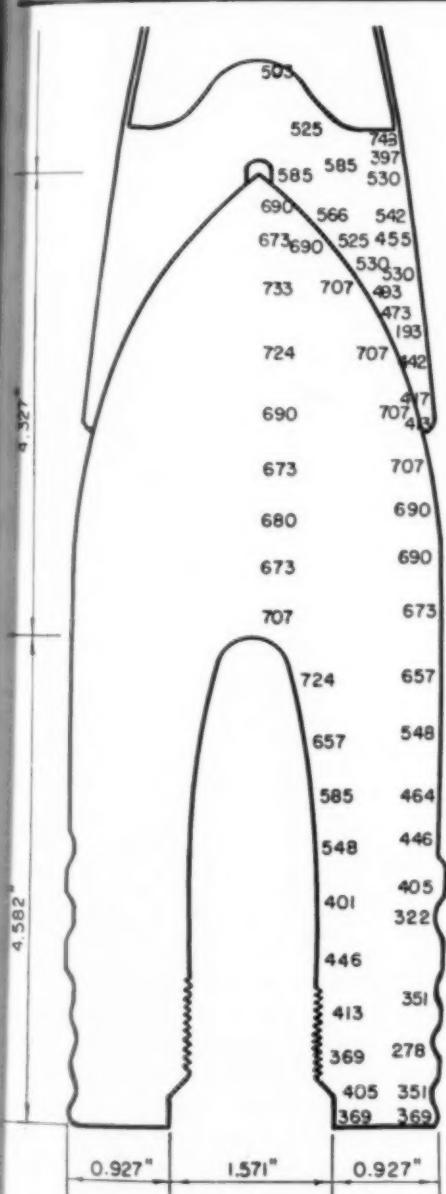
Fig. 4 — Hardness Survey Across Diameter of German 88-Mm. Armor Piercing, Capped Projectile. Vickers diamond hardness, 10-kg. load
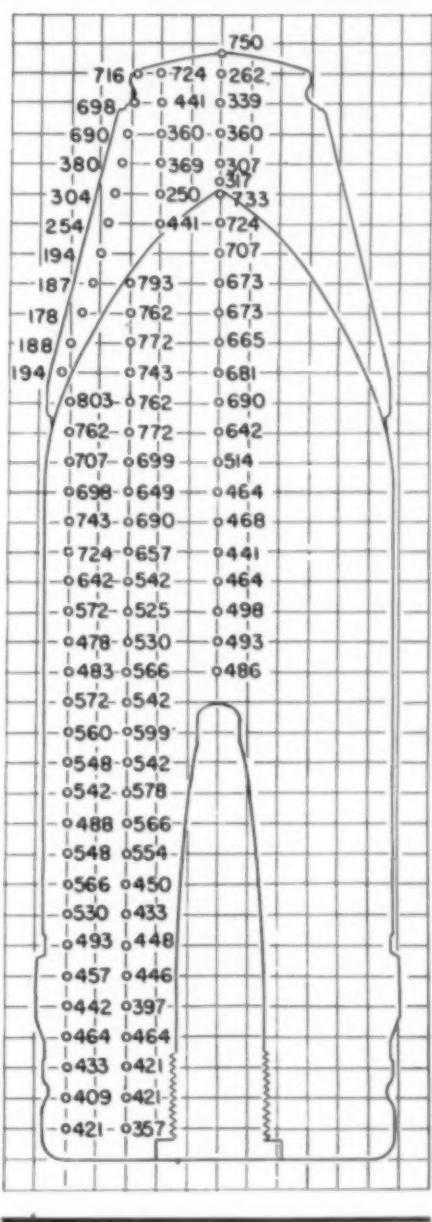
The carbon in some unwelded projectiles then rose to 1% with, say, 1.35% Cr, 0.05 to 0.40% Ni residual, 0 to 0.20% V. The cap stayed around the 0.45% C level, usually having 1½% Cr.

Uncapped, solid, unwelded, 20-mm. A.P. shot differentially tempered and made from chromium steel show the analyses given in Table V. The use of the very high carbon, high chromium steel of the 1939 projectile seems to have been temporary and in recent years a return was made to the 1938 composition.

A 105-mm. armor-piercing, capped, ballistically-capped, unwelded, differentially tempered round made in 1941 still carried a copper rotating band. The cap and projectile body analyzed as shown in the middle of Table V, and in this instance the chromium is bolstered up by extra manganese and silicon.

During the duplex driving band era the welded projectile came in, apparently because the desired hardness at the tip, for which 1% carbon

and an appreciable amount of nickel were present together. When the steel was fairly high in the molybdenum and vanadium, the chromium was often lowered, say to 1.15%, but the residual nickel did not appear to be taken into account.

The same shell might have vanadium but no molybdenum in the cap; no molybdenum or vanadium in the tip; and 0.20% molybdenum but no vanadium, or both molybdenum and vanadium in the base — or any other combination. It seems as though the Germans liked to use molybdenum or vanadium, and perhaps would prefer both together, and used them when they were available, but got along without them when they were not. In some 75-mm. Pak 40 A.P., C., B.C. projectiles of this type, dated 1942, the cap is plain carbon steel and the nose and base of the usual high chromium steel, but without molybdenum, thus indicating a growing tendency to save the latter metal at that time.

Another type of armor-piercing projectile

#### Table V — Analyses of Heat Treated Armor-Piercing Projectiles

| Year | Type | C | P | S | Mn | Si | Ni | Cr | Mo | Cu | Sn | As | V |
|------|------|---|---|---|----|----|----|----|----|----|----|----|---|
| | Uncapped, Solid, Unwelded, 20-Mm. Armor-Piercing Shot, Differentially Tempered | | | | | | | | | | | | |
| 1938 | German | 0.93 | 0.016 | 0.028 | 0.38 | 0.18 | 0.09 | 1.25 | 0.07 | 0.17 | 0.04 | 0.005 | — |
| 1939 | German | 2.15 | 0.018 | 0.010 | 0.21 | 0.45 | 0.10 | 3.28 | tr. | 0.19 | 0.06 | 0.015 | 0.01 |
| 1941 | Italian | 1.01 | 0.014 | 0.012 | 0.50 | 0.25 | 0.16 | 1.71 | tr. | 0.02 | 0.02 | 0.006 | — |
| 1942 | German | 0.89 | 0.019 | 0.035 | 0.94 | 0.34 | 0.06 | 1.16 | tr. | 0.28 | 0.04 | 0.011 | — |
| | 105-Mm. Armor-Piercing Capped, Ballistic-Capped, Unwelded, Differentially Tempered | | | | | | | | | | | | |
| 1941 | Cap | 0.53 | 0.023 | 0.027 | 1.02 | 0.73 | 0.10 | 1.00 | 0.04 | 0.19 | 0.02 | 0.01 | — |
| 1941 | Body | 0.54 | 0.025 | 0.025 | 1.14 | 0.78 | 0.08 | 1.21 | 0.05 | 0.18 | 0.03 | 0.01 | — |
| | Welded 50-Mm. Armor-Piercing, High Explosive Shell | | | | | | | | | | | | |
| 1940 | Nose | 0.98 | 0.011 | 0.011 | 0.30 | 0.21 | 0.11 | 1.38 | 0.02 | 0.18 | 0.05 | 0.01 | tr. |
| 1940 | Base | 0.32 | 0.018 | 0.010 | 0.66 | 0.25 | 0.15 | 1.12 | 0.17 | 0.16 | tr. | 0.01 | tr. |
| 1941 | Nose | 1.01 | 0.010 | 0.007 | 0.37 | 0.28 | 0.08 | 1.33 | 0.02 | 0.16 | 0.02 | 0.02 | tr. |
| 1941 | Base | 0.30 | 0.021 | 0.018 | 0.70 | 0.27 | 0.12 | 1.09 | 0.33 | 0.17 | 0.04 | 0.01 | 0.07 |

was considered essential, was incompatible with the desired toughness at the base, especially in the larger caliber projectiles; consequently the nose was held at 1% carbon and the base at around 0.40%, both with about 1¼% chromium. The caps might be the 3½% Ni, 1% Cr type or the plain 1½% Cr steel, quenched and differentially tempered or, as in Fig. 5, of carbon steel flame-hardened on the end.

The residual nickel varied, in the cap, nose, and base, from a mere trace to 0.5%, but more generally was not over 0.10%. Great variability was shown in molybdenum and vanadium. Sometimes no molybdenum at all was present, sometimes it was 0.07 to 0.13% — probably residual — at others 0.20% or above, which, accompanied by low nickel, indicated an intentional addition. Vanadium was either absent, or at anything up to 0.20%; sometimes this amount of vanadium

lacks the penetrating cap, but — like those discussed above — has the nose welded to the base. Welded 50-mm. armor-piercing, high explosive projectiles were made of the steels shown in the bottom four lines of Table V.

That plenty of scrap was used in the melting of this steel is shown by the residual copper and tin, but the low nickel indicates that what alloy scrap was used may have been of chromium-molybdenum steel from which the residual molybdenum was utilized — although the base of the shell dated 1941 doubtless had an intentional addition of molybdenum. Nevertheless, molybdenum-bearing scrap is evidently not allowed to drift into general scrap, as the generally low residual amount of this element shows.

This fact, together with the low level of nickel in non-alloyed steels and the comparative rarity of much over 0.10 to 0.15% nickel even in

112    181    189
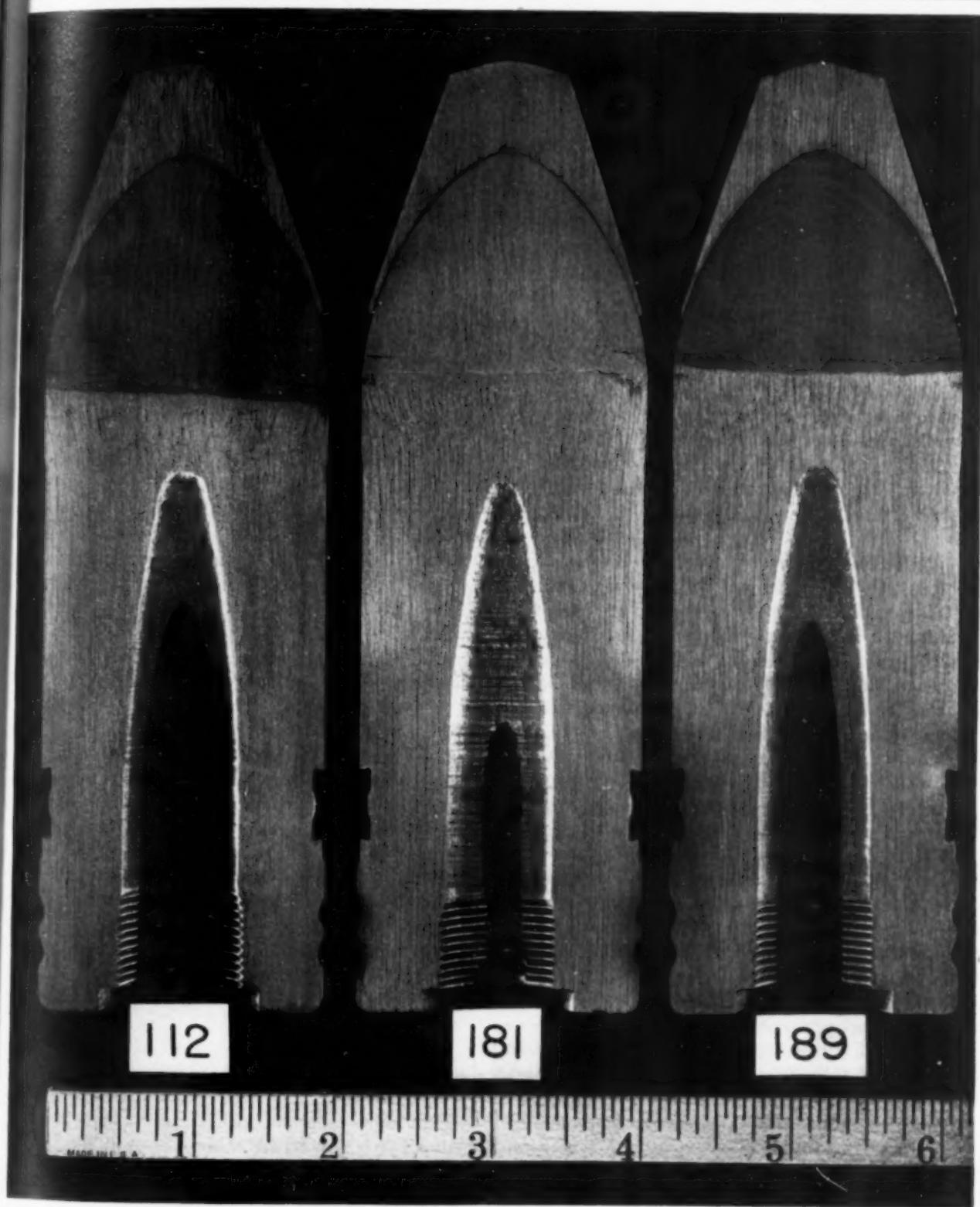
Fig. 6 — Macro-Etched Sections of Duplex Welded A.P. Projectiles, 50-Mm.
Caliber, Show Perfect Welds But Many Quench Cracks in Hard Nose

alloy steels, argues that the Germans are in no position to fall back on a reservoir of residual nickel and molybdenum in their scrap so as to produce analogues to our NE steels. Instead, they build up their alloy steels on a chromium basis, with a strong tendency to use molybdenum as an auxiliary element. Manganese, too, is obviously used as an alternate to chromium.

Manganese is not so prominent in the German alloy picture as chromium, and there appears to be some effort to hold it to the lowest practical level consistent with the metallurgical results aimed at — as though the Germans had, at most times, somewhat more need to conserve manganese than chromium; however, this effort is not always made.

Silicon may be raised to a definitely alloying amount as another partial alternate alloy, and is so used often enough to show that its use is understood, but rarely enough to indicate that such use may not be too popular and perhaps something of a last resort.

The use of vanadium in these projectiles is spotty. Some iron ores which have been available to the Germans carry small amounts of vanadium, most of which is recovered from the pig iron by slagging off in a converter or mixer.[21] The vanadium is recovered from the slag by special methods that must make the metal very expensive in man-hours. The supply of vanadium from this source probably fluctuates and this fluctuation may account for the erratic way in which it appears or fails to appear in the finished steel. When it does appear, it is often in a surprisingly high amount for the type of steel under study.

## Projectiles With Tungsten Carbide Cores

The general use of molybdenum in what we would term high proportions and the occasional lavish use of vanadium suggest that the Germans have very adequate supplies or stockpiles of tungsten for high speed toolsteels and carbide tools. Certainly the most vital role of tungsten is in these cutting tools which so vastly speed-up machine shop production. If tungsten is scarce enough so that much conservation of and substitution for it in high speed toolsteel were necessary, this would be accomplished by raising the vanadium content and substituting molybdenum for part of the tungsten — expedients which we in America adopted early in the war, and with which German metallurgists are well acquainted.

But the Germans have had tungsten to shoot away, for certain very high velocity armor-piercing projectiles carry a core made of tungsten carbide! The extreme hardness of tungsten car-

bide gives penetrating power, if the impact of the projectile has enough energy behind it. The "push" is the product of mass times the square of the velocity; so mass is important even at high velocity, and to get mass in a small projectile the projectile has to have high density, and tungsten carbide has that.

The 76.2-mm. shot of this sort is of conventional exterior, with a steel body carrying a driving band, and topped by a thin aluminum alloy ballistic cap. Back of this ballistic cap is another ballistic shape, of molded plastic, which not only provides a pointed ballistic tip but also fills the space between the shell body and another tubular steel fitting, screwed into the base of the body proper, and holding the back end of the tungsten carbide core.

The 47 or 50-mm. armor-piercing shot (and those of somewhat smaller caliber, as the 37-mm. have what amounts to two driving bands in the form of projections on the steel projectile body. Those used in the usual type of barrel have the front projection as a prolongation of the arrowhead shape of the cap; the rear projection is normal to the axis and slightly relieved in the middle of the projection, as shown in examples 163 and 164 of Fig. 7. The steel bodies have 0.06 to 0.12% C, 0.50 to 0.70% Mn, and a trace of Si. This steel is aluminum-killed and carries low residuals (about 0.04% Ni, 0.05% Cu, and only traces of others). Sulphur and phosphorus are sometimes low, but more generally the steel is a free-machining type with 0.04 to 0.06% P, and 0.20 to 0.30% S.

The base of the tungsten carbide core rests in a hollow in the steel body, its tip in a cap which may be either plastic or an aluminum alloy. When aluminum is used, the material appears to be remelted duralumin-type scrap, with the addition of somewhere around 0.5% of either lead or bismuth (or both) for free-machining properties.

There is also a 20-mm. Solothurn armor-piercing shot in which the tungsten carbide core is embedded in a duralumin-type body equipped with a driving band.

The most interesting projectile of this general type is that shown at the top of Fig. 7 (samples No. 155 and 159) for use in the 28/20-mm. tapered bore Gerlich high velocity gun. (This gun has a 28-mm. bore at the breech, tapering to 20 mm. at the muzzle.) The "driving bands" of the steel projectile body are designed to close in, umbrella fashion, as the projectile passes through the bore. Both front and rear "bands" are, therefore, given arrowhead shape. The front one has a few holes in it to let gas
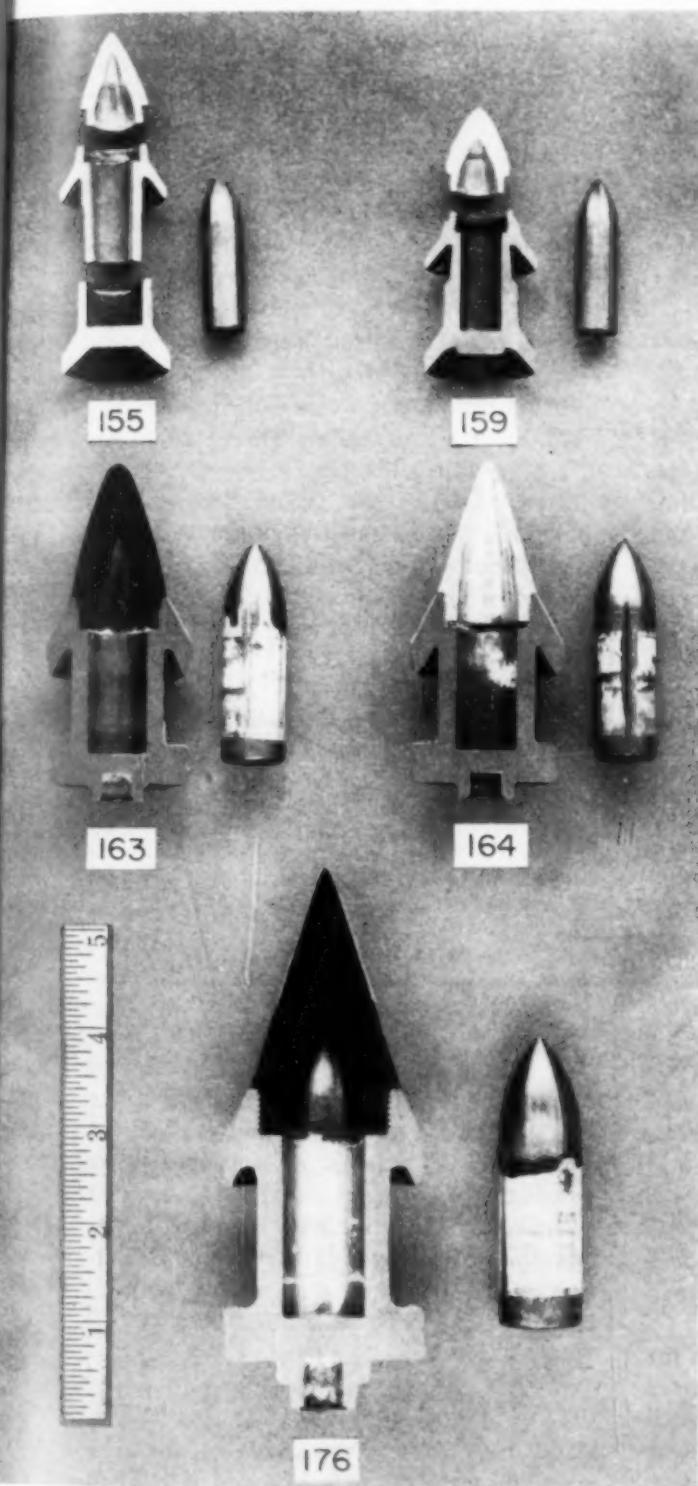
Fig. 7 — German Arrowhead Projectile With Tungsten Carbide Cores. Wings act as driving bands. Samples 155 and 159 are shot for the Gerlich 28/20-mm. taper-bore, high velocity gun

escape as the flange closes down on the body. The nose of the projectile is sometimes made of magnesium.

One would suspect rapid wear of the gun bore with solid iron "driving bands" rubbing against the ordinary barrel, and, of course, terrifically rapid wear in the taper-bored Gerlich gun. Possibly the high sulphur content of the steel bodies, of which these "bands" form a part, may tend to mitigate galling of the barrel, as well as provide machinability.

A Gerlich 28/20-mm. barrel made in 1941, in which an unknown number of rounds had been fired, but in which the metallographic examination of the "white layer" indicated that erosion was not progressing very badly, contained 0.38% C, 0.029% P, 0.027% S, 0.57% Mn, 0.25% Si, 0.35% Ni, 2.29% Cr, 0.27% Mo, 0.15% Cu, 0.05% Sn, and a trace of aluminum. Here again we have the familiar chromium-molybdenum steel, this time with very high chromium. The barrel showed 105,000 to 110,000-psi. yield strength, 137,500-psi. tensile strength, 20% elongation, 60% reduction in area, and had been heat treated to around 200 to 250 Vickers hardness. In the used condition, the hardness increased progressively along the bore, the lands at the muzzle going up to 300 to 330 Vickers, probably by cold working in use.

The tungsten carbide cores are quite different from the usual sintered carbide tool or wire-drawing die. They are far too brittle for use as tools, but with the base embedded in and reinforced by the steel socket and the tip covered with plastic or aluminum until it reaches the armor, the core evidently stands up under the high velocity impact long enough to penetrate — although if unsupported and stressed at a lower velocity it would crumble. The Germans do not care how brittle a driving band or a carbide core may be under tests that do not duplicate service. Once they find that something really works in service, the results of non-representative tests do not deter them from trying it.

#### Table VI — German Steels Used in Heavy Machine Guns and Automatic Rifles

| Date | Caliber and Mark | C | P | S | Mn | Si | Ni | Cr | Mo | Cu | Sn | Al | V |
|------|-----------------|------|-------|-------|------|------|------|------|------|------|------|-------|------|
| 1942 | 13 mm., MG 131 | 0.67 | 0.007 | 0.006 | 0.36 | 0.21 | 2.46 | 1.14 | 0.24 | 0.17 | 0.03 | 0.005 | — |
| ? | 15 mm., MG 151/15 | 0.38 | 0.023 | 0.021 | 0.66 | 0.21 | 0.14 | 2.08 | 0.31 | 0.20 | 0.05 | 0.01 | 0.02 |
| ? | 20 mm., MG 151/20 | 0.32 | 0.202 | 0.012 | 0.54 | 0.26 | 0.27 | 1.92 | 0.30 | 0.19 | 0.05 | 0.005 | 0.01 |
| 1941 | 20-mm. Oerlikon | 0.36 | 0.016 | 0.088 | 0.34 | 0.29 | 2.48 | 1.16 | 0.32 | 0.23 | 0.02 | 0.005 | 0.01 |

The carbide cores were originally made by powder metallurgical and sintering methods analogous to those used for carbide tools, although the amount of admixed metal binder was much smaller, and the usual binder for carbide tools (cobalt) was not used.

At first the metal binder was mostly nickel (0.75 to 2.5% of the entire mass) with a little iron. The Germans were apparently willing to shoot away lots of tungsten but they may have begrudged 1% nickel, even though brass cartridge cases were used for this class of ammunition, and copper driving bands were the rule — the ammunition being valuable enough to justify taking no chances on rusting. The 1940 cores in various sizes had 92 to 94% tungsten with only a trace of columbium, about 4¾% carbon, ½ to 1½% nickel, ½ to 1¼% iron. They had a density of 15.6 to 15.9, and a Rockwell hardness of A-80 to 92.

Finally, in 1941 and 1942 a "cast" carbide core was made in which no nickel was used; the tungsten ran about 93½%, the columbium 1.75 to 2.75%, the carbon about 4%, the iron ½ to 1¼%, the density 15.4 to 15.8, and the Rockwell hardness A-86 to 91. The "cast" cores were excessively brittle, and contained not only the compound WC but also some $W_2C$. This "casting" is doubtless not melting and pouring, but melting down the ingredients by arc or induction heating into a bullet-shaped graphite mold.

It is well known, as Hinnuber[12] shows for wire drawing dies, that "cast" carbide is more brittle than the bonded and sintered type, but experience probably showed that brittleness was of little moment in this use, and production was probably facilitated by going to the "cast" type.

From this lavish use of tungsten, from which there is no scrap recovery, it seems probable that the reserve stock of tungsten was so huge that cutting off incoming shipments might affect the continued production of armor-piercing carbide cores but could not prevent the continued use of carbide tools and high speed steels. Moreover, the rather lavish use of molybdenum indicates that that stockpile also was huge and could be called upon to eke out the tungsten necessary for high speed steel. Molybdenum is not lost in remelting, and all of this metal in the scrap revolves without loss.

The amount of chromium used in the heat treatable steels is high. Much of the chromium is lost on remelting in the openhearth — less in electric melting, but still appreciable. Unless there is a vast stock of chromium in storage, cutting off the imports might make it a bit difficult for German metallurgists. They would eke out a shortage of chromium by molybdenum and by

#### Table VII — Steels Used in German Field Guns

| Date | Caliber | C | P | S | Si | Mn | Ni | Cr | Mo | Cu | V |
|------|---------|------|------|------|------|------|------|------|------|------|------|
| 1941 | 50 mm. | 0.38 | 0.03 | 0.04 | 0.30 | 0.68 | 0.20 | 2.63 | 0.13 | 0.17 | — |
| 1942 | 50 mm. | 0.41 | 0.02 | 0.02 | 0.31 | 0.66 | 0.05 | 2.22 | 0.32 | 0.10 | — |
| 1942 | 50 mm. | 0.38 | 0.01 | 0.02 | 0.40 | 0.44 | 0.65 | 2.41 | 0.35 | 0.13 | 0.11 |
| 1942 | 170 mm. | 0.41 | 0.02 | 0.02 | 0.29 | 0.51 | 1.57 | 2.75 | 0.34 | 0.08 | — |
| 1942 | (a) 47 mm. | 0.34 | 0.01 | 0.02 | 0.31 | 0.53 | 3.00 | 1.00 | 0.31 | 0.11 | — |
| 1937 | (b) Tube | 0.32 | 0.02 | 0.03 | 0.44 | 0.46 | 2.44 | 1.39 | 0.32 | ι ·? | — |
| 1937 | (b) Jacket | 0.38 | 0.03 | 0.02 | 0.42 | 0.42 | 0.29 | 1.20 | 0.06 | 0.04 | — |

(a) Czech gun. (b) Watertown Arsenal data on Russian 76-mm. tube captured and used by the Germans.

increasing the manganese in their steels as long as these alloying metals are available, and they could turn to silicon in a pinch. They might resort to "needling" — that is, to boron additions to increase hardenability, but how far they have advanced in knowledge of the use of boron is not known. What they do know does not get published in current technical literature.

## Metal in German Guns

**Rifles** — The Germans, of course, use alloy steel for certain gun parts, and it is of interest to examine how far the tendencies and changes in analyses, commented on above as indicated by armor and ammunition, hold true in guns. In a Mauser rifle (7.92-mm. Markiner 98K) made in 1941, all parts, including the barrel, were of carbon steel with residuals of 0.06 to 0.11% Ni, 0.02

to 0.25% Cr, 0.01 to 0.12% Mo, 0.03 to 0.30% Cu, and trace to 0.06% Sn. Despite the large amount of machining on many parts of relative unimportance, no free-machining steels were used. Many parts that could well be made by stamping were machined out of the solid. A plywood stock was used.

A semi-automatic rifle of 1941 — 7.92-mm. Gewehr 41 (W) — showed much the same situation, having no alloy steels and low residuals.

**Machine Guns** — A 1941 MG-34 machine gun has a few bolts of cold drawn steel, a few stampings, and a carbon steel barrel, all with low residuals. The bulk of all the some 200 parts in the gun were, likewise, of ordinary carbon steel. The exceptions were the breech lock, feeding lever slide, sear, bolt, and bolt slide; these were all carburized wearing parts for which 3.5% Ni, 0.75% Cr, 0.05 to 0.20% Mo carburizing steel was employed.

The barrels of six 7.92-mm. aircraft machine guns manufactured in the consecutive years 1934 to 1942 were all plain carbon steels with low residuals. Heavier barrels were made of the steels shown in Table VI, page 302.

A PzB 7.92-mm. anti-tank rifle made in 1941 had a carbon steel barrel, a few stampings and a few parts made from free machining steel. Of some 130 parts examined only one, the firing pin guide, was of the nickel-chromium carburizing steel mentioned above. The other carburized parts were plain carbon steel.

A Schmeisser 9-mm. submachine gun for paratrooper use, made in 1941, was all carbon steel with still more use of stampings and of free machining steel.

A 20-mm. MG-151 Mauser aircraft machine gun, probably made in 1941, had a barrel which analyzed 0.40% C, 0.65% Mn, 0.29% Si, 0.32% Ni, 2.07% Cr, 0.23% Mo. Several important wearing parts were made of nickel-chromium carburizing steel ranging from 3.36 to 4.58% Ni, 0.55 to 1.33% Cr, and 0.02 to 0.19% Mo. These together weighed about 10 lb., that is, they used about 0.4 lb. nickel. The barrel weighed 23 lb., so the choice of the 2% chromium steel instead of the 2½% nickel steel for the barrel is a conservation measure. Barrels of MG-151 guns of 15-mm. caliber were made of similar chromium-molybdenum steel, although barrels of the 13-mm. MG-131 and the 20-mm. Oerlikon, made in 1942 and 1941 respectively, contained 2½% Ni, 1% Cr, and 0.3% Mo. There is evidence that all of these large caliber machine gun barrels have been treated with vanadium although only 0.01 to 0.02% remains.

In a 15-mm. MG-151 machine gun, probably of quite recent manufacture, the same carburized parts were of even more uniform composition than in the 20-mm. MG-151 described in the paragraph above, with 0.15 to 0.25% C, low phosphorus and sulphur, 0.40 to 0.50% Mn, 0.25 to 0.35% Si, 3.40 to 3.65% Ni, 0.70 to 0.95% Cr, 0.13 to 0.18% Mo (save for one cam which had only a 0.02% residual molybdenum).

In larger caliber aircraft machine guns, the heavily stressed wearing parts are of the high nickel-chromium, or nickel-chromium-molybdenum carburized steel, as in the 20-mm. caliber. Nickel is evidently treasured for special uses, but when they do use it for carburized parts they tend to stick to the old Krupp high-nickel formula.

Because of the high rate of fire, the scour on machine gun barrels — particularly in the larger calibers — is very severe, but the problem of thorough hardening in heat treatment is not as difficult as in the case of heavy ordnance.

**Table VIII — Analysis of Steels in Principal Parts of 88-Mm. German Gun, Made in 1941**

| PART | C | Mn | P | S | Si | Ni | Cr | Mo | V | Cu | Al |
|------|------|------|-------|-------|------|------|------|------|------|------|------|
| Tube (center) | 0.39 | 0.44 | 0.016 | 0.014 | 0.36 | 2.74 | 1.36 | 0.35 | tr. | 0.22 | Nil |
| Tube (muzzle) | 0.34 | 0.38 | 0.018 | 0.020 | 0.40 | 2.83 | 1.40 | 0.48 | 0.06 | 0.19 | Nil |
| Sleeve (a) | 0.36 | 0.50 | 0.011 | 0.021 | 0.32 | 0.20 | 2.04 | 0.32 | tr. | 0.16 | 0.01 |
| Jacket (a) | 0.36 | 0.46 | 0.008 | 0.022 | 0.36 | 2.82 | 1.52 | 0.51 | tr. | 0.20 | 0.01 |
| Retaining collar | 0.35 | 0.57 | 0.010 | 0.021 | 0.42 | 2.77 | 1.26 | 0.31 | Nil | — | — |
| Muzzle locking collar | 0.35 | 0.53 | 0.010 | 0.025 | 0.42 | 1.12 | 1.19 | 0.29 | tr. | — | — |
| Breech ring | 0.31 | 0.57 | 0.014 | 0.016 | 0.39 | 0.50 | 1.97 | 0.31 | tr. | 0.18 | 0.01 |
| Key (tube, center) | 0.32 | 0.44 | 0.014 | 0.017 | 0.39 | 0.39 | 1.80 | 0.31 | tr. | — | — |
| Key (tube, muzzle) | 0.31 | 0.48 | 0.013 | 0.024 | 0.41 | 2.68 | 1.04 | tr. | tr. | — | — |

*(a)* Average of analyses from breech and muzzle ends.

**Field Guns** — Little information on heavy German artillery is at hand; samples are not easy to collect or ship. German gun tubes of larger caliber made in 1941 and 1942, which are being examined at Massachusetts Institute of Technology, analyze as shown in Table VII, page 302.

The 1941 50-mm. tube has relatively low molybdenum, but the 1942 examples have the usual liberal amount, one has vanadium also.

The 170-mm. tube shows that some nickel has been hoarded for special use. The very high nickel in the 47-mm. gun of Czech manufacture, used by the Germans, shows, by contrast with the German 50-mm. gun, how much nickel the Germans are conserving over former common practice by shifting to the chromium-molybdenum type of steel.

A German 88-mm. gun, made in 1941, examined by Watertown Arsenal showed the following steels in principal parts (Table VIII, page 303). These show the use of both nickel-chromium-molybdenum and chromium-molybdenum steels. The increased silicon content probably offsets the lowered manganese content.

**Table IX — Analyses of Steels Used in Typical Japanese Projectiles and Bombs**

| DATE | TYPE OF PROJECTILE | C | P | S | MN | SI | NI | CR | MO | CU | SN | AL | OTHER |
|------|--------------------|---|---|---|----|----|----|----|----|----|----|----|-------|
| None | 75-mm. H. E. | 0.50 | — | — | 0.41 | 0.28 | 0.85 | 0.33 | 0.02 | 0.13 | 0.03 | 0.005 | |
| 1940 | 80-mm. H. E. (Naval) body | 0.48 | 0.01 | 0.02 | 0.51 | 0.22 | 0.92 | 0.32 | 0.02 | 0.16 | 0.04 | 0.01 | |
| 1940 | Same; base plug | 0.57 | 0.02 | 0.02 | 0.78 | 0.19 | 0.83 | 0.36 | 0.02 | 0.21 | 0.05 | tr. | |
| 1941 | 80-mm. H. E. (Naval) body | 0.58 | 0.05 | 0.04 | 0.57 | 0.14 | 0.68 | 0.05 | 0.02 | 0.28 | 0.01 | 0.005 | |
| 1941 | Same; base plug | 0.48 | 0.07 | 0.04 | 0.62 | 0.15 | 0.40 | 0.02 | 0.02 | 0.27 | 0.02 | 0.005 | |
| 1934 | 15-kg. anti-personnel bomb nose | 0.09 | 0.01 | 0.02 | 0.71 | 0.27 | 0.32 | 0.04 | 0.01 | 0.16 | 0.02 | 0.01 | 0.07 W |
| 1934 | Internal section of same | 0.34 | 0.03 | 0.07 | 0.28 | tr. | 0.04 | 0.03 | tr. | 0.37 | 0.03 | 0.005 | |
| 1934 | Annular rings from same | 0.25 | 0.01 | 0.02 | 0.49 | 0.01 | 0.05 | 0.03 | tr. | 0.19 | 0.03 | 0.005 | |
| 1939 | 30-kg. anti-personnel bomb nose | 0.32 | 0.01 | 0.03 | 0.56 | 0.22 | 0.23 | 0.04 | tr. | 0.28 | 0.06 | tr. | |
| 1939 | Tail cone from same | 0.24 | 0.04 | 0.06 | 0.77 | 0.15 | 0.30 | 0.05 | 0.01 | 0.30 | 0.06 | 0.01 | |
| 1938 | 50-kg. anti-personnel bomb nose | 0.52 | 0.02 | 0.03 | 0.86 | 0.25 | 0.06 | 0.03 | tr. | 0.30 | 0.12 | 0.005 | |
| 1938 | Bomb body from same | 0.14 | 0.02 | 0.02 | 0.50 | 0.29 | 0.04 | 0.03 | tr. | 0.16 | 0.05 | 0.01 | |
| 1938 | Tail cone from same | 0.30 | 0.04 | 0.03 | 0.73 | 0.16 | 0.03 | 0.03 | tr. | 0.31 | 0.06 | 0.005 | |
| 1942 | 25-mm. Hotchkiss incendiary | 0.55 | 0.02 | 0.03 | 0.65 | 0.32 | 0.08 | 0.03 | tr. | 0.20 | 0.08 | 0.05 | |
| 1943 | Same | 0.58 | 0.02 | 0.03 | 0.65 | 0.30 | 0.11 | 0.45 | 0.01 | 0.24 | 0.06 | 0.02 | |
| 1942 | Same (tracer) | 0.52 | 0.04 | 0.04 | 0.74 | 0.28 | 0.05 | 0.03 | tr. | 0.25 | 0.04 | 0.01 | |
| 1943 | Same (tracer) | 0.58 | 0.02 | 0.03 | 0.72 | 0.24 | 0.28 | 0.06 | 0.01 | 0.34 | 0.08 | 0.01 | |
| None | 63-kg. semi-armor-piercing bomb body | 0.46 | 0.02 | 0.03 | 0.52 | 0.34 | 1.43 | 0.46 | tr. | 0.23 | 0.06 | 0.005 | |
| " | Same, tail body | 0.26 | 0.04 | 0.02 | 0.58 | 0.17 | 1.29 | 0.44 | tr. | 0.18 | 0.11 | 0.015 | |
| " | Same, tail body | 0.19 | 0.04 | 0.08 | 0.46 | 0.19 | 0.04 | 0.03 | tr. | 0.26 | 0.16 | 0.005 | |
| " | Same, tail fins | 0.19 | 0.06 | 0.01 | 0.33 | tr. | 0.03 | 0.02 | tr. | 0.19 | 0.14 | (a) | |
| 1941 | 70-mm. H. E., body | 0.64 | 0.03 | 0.04 | 0.67 | 0.20 | 0.03 | 0.02 | tr. | 0.22 | 0.11 | tr. | |
| 1939 | 37-mm. H. E. | 0.53 | 0.03 | 0.03 | 0.76 | 0.20 | 0.04 | 0.03 | tr. | 0.27 | 0.14 | 0.005 | |
| None | 20-mm. Oerlikon H. E., tracer | 0.28 | 0.04 | 0.10 | 1.09 | 0.12 | 0.09 | 0.03 | tr. | 0.28 | 0.07 | tr. | 0.025 Ti |
| 1941 | 20-mm. Oerlikon H.E. | 0.48 | 0.04 | 0.02 | 0.52 | 0.42 | 0.43 | 0.41 | 0.14 | 0.32 | 0.09 | 0.01 | 0.04 Ti |
| 1942 | Same | 0.33 | 0.06 | 0.14 | 1.02 | 0.18 | 0.05 | 0.03 | tr. | 0.15 | 0.05 | 0.015 | 0.025 Ti |
| 1941 | 20-mm. Oerlikon tracer, A.P. (b) | 0.31 | 0.03 | 0.12 | 1.22 | 0.21 | 0.08 | 0.04 | tr. | 0.16 | 0.04 | 0.01 | 0.025 Ti |
| 1942 | 20-mm. H. E. for Hotchkiss machine gun | 0.39★ | 0.13★ | 0.06 | 0.71 | 0.21 | 0.04 | 0.02 | tr. | 0.24 | 0.06 | tr. | 0.025 Ti |
| 1942 | 20-mm. A.P. Hotchkiss tracer (b) | 0.85 | 0.01 | 0.02 | 0.47 | 0.29 | 0.33 | 0.60 | 0.02 | 0.30 | 0.06 | 0.03 | (c) |
| None | 20-mm. A.P. (d) | — | — | — | 0.40 | 0.32 | 0.05 | 1.26 | tr. | 0.18 | 0.06 | 0.03 | 0.01 Ti |
| 1938 | 120-mm. Naval bombardment H.E. body | 0.51 | 0.02 | 0.02 | 0.70 | 0.33 | 0.87 | 0.36 | tr. | 0.15 | 0.03 | tr. | (e) |

NOTES: ★High phosphorus for this level of carbon. Several of this 20-mm. series are evidently intended to be free-machining steels, but so high a phosphorus content in so high a carbon steel is quite unusual.

(a) Rimmed steel.

(b) Quenched and differentially tempered; armor piercing.

(c) Trace of titanium, 2.25% tungsten, 0.25% vanadium.

(d) Quenched and tempered.

(e) 0.005% titanium, 0.01% vanadium.

## Japanese Arms and Ammunition

Less information about Japanese ordnance is at hand, especially as to material of recent manufacture, for the Japs have been making munitions in preparation for the present conflict for a long time, and have not used their supply as rapidly as the Germans did.

Nevertheless, what data are available do not indicate as careful attention to conservation of alloying elements as the Germans observe. The data also show, from the much higher content of residuals, especially tin, that the low grade scrap the Japs were supplied from the United States during the years immediately preceding the War plays a considerable part in the munitions now being used against us.

The rather frequent use, in as-forged or normalized articles, of steels made from scrap carrying a high level of residual elements that, properly used, would confer hardenability for heat treatment by quenching and tempering, indicates indifference to such a waste of alloying elements, or inability to control steelmaking well enough to make use of them.

The general level of hardenability-conferring residuals in the scrap used for carbon steel is often quite low; when it rises high it probably means that a considerable proportion of scrap was used. Evidently this scrap was bought from us in mixed lots, in which alloy scrap was not segregated from carbon scrap, so the Japs cannot predict the alloy content of the scrap charged in any one heat. In American steelmaking practice rapid spectrographic analyses would find the residual alloy content while the steel is still in the furnace so the desired alloy additions could be calculated and safely added; but there is no sign that the Japs have progressed far enough to use that technique.

Moreover, there is considerable evidence that they have felt no need to take any steps along the line of our NE steels, or to hold down the percentage of alloying elements when intentional alloying is done.

Their driving bands are copper (or with 2% silicon on some high velocity projectiles); their cartridge cases, brass. The cartridge cases are sometimes alpha brass of the conventional 70:30 composition, but often of higher zinc content than other countries use, even to the extent of producing an alpha-beta brass and thus introducing more complications in processing. This does not seem to reflect a desire to conserve copper, but rather a long tradition of Oriental use and experience with the alpha-beta type.

**Projectiles and Bombs** — High alloy content in unquenched articles, a wide range of residual contents, but a strong tendency to show a high tin residual, are present in some of the examples cited in Table IX, page 304.

There seems little justification for the nickel and chromium levels in several of the non-quenched items listed. The prevalence of high tin residuals will be noted.

In the case of a 50-mm. grenade discharger made in 1942, containing several heat treated parts, mostly small, carbon steels with residuals of 0.03 to 0.06% Ni, 0.02 to 0.08% Cr, 0.01% Mo, 0.10 to 0.30% Cu, 0.01 to 0.09% Sn, and containing about 0.01% Al, were used, but the quenched

Table X — Analyses of Japanese 50-Mm. Grenade Parts (a)

| DATE | PART | HEAT TREATMENT | C | P | S | MN | SI | CU | SN | AL |
|------|------|----------------|------|------|------|------|------|------|------|------|
| 1938 | Propelling charge housing | Quenched & tempered | 0.63 | 0.06 | 0.04 | 0.85 | 0.18 | 0.27 | 0.04 | tr. |
| 1939 | Same | Same | 0.55 | 0.03 | 0.03 | 0.88 | 0.19 | 0.22 | 0.04 | tr. |
| 1940 | Same | Same | 0.72 | 0.02 | 0.04 | 0.66 | 0.18 | 0.27 | 0.07 | tr. |
| 1941 | Same | Same | 0.59 | 0.02 | 0.03 | 0.55 | 0.21 | 0.20 | 0.06 | tr. |
| 1938 | Threaded connector | Normalized | 0.33 | 0.05 | 0.04 | 0.76 | 0.11 | 0.30 | 0.03 | tr. |
| 1939 | Same | Quenched & tempered | 0.35 | 0.04 | 0.03 | 0.76 | 0.18 | 0.33 | 0.11 | 0.01 |
| 1940 | Same | Same | 0.35 | 0.03 | 0.02 | 0.76 | 0.17 | 0.19 | 0.03 | 0.005 |
| 1941 | Same | Same | 0.34 | 0.05 | 0.02 | 0.69 | 0.18 | 0.21 | 0.06 | 0.005 |
| 1938 | Body | Normalized | 0.29 | 0.04 | 0.03 | 0.80 | 0.14 | 0.25 | 0.08 | 0.005 |
| 1939 | Same | Same | 0.23 | 0.02 | 0.04 | 0.77 | 0.19 | 0.17 | 0.04 | 0.005 |
| 1940 | Same | Same | 0.31 | 0.02 | 0.02 | 0.57 | 0.22 | 0.15 | 0.04 | 0.02 |
| 1941 | Same | Same | 0.26 | 0.03 | 0.02 | 0.58 | 0.17 | 0.22 | 0.04 | 0.015 |

(a) All showed 0.05 to 0.06% Ni, 0.03 to 0.05% Cr, and trace of Mo.

and tempered breech block contained 0.43% C, 0.04% P, 0.04% S, 0.50% Mn, 0.20% Si, 1.69% Ni, 0.44% Cr, 0.03% Mo, 0.40% Cu, 0.11% Sn, and trace of Al. The steel parts of 50-mm. grenades analyzed as shown in Table X, page 305.

A Japanese 81-mm. mortar shell, shown in Fig. 8, was well forged from a 0.35% carbon steel with manganese at 0.65%. No heat treatment was applied.

There may be hints here, from the lower level of manganese in the later years, that some effort is being made to conserve it, and that aluminum treatment is now being applied to steels for normalizing.

**Rifles and Machine Guns** — The quenched and tempered barrel, breech and bolt of a 7.7-mm. Arisaka rifle, Model 99 (1939) undated, captured on Attu, and the cut-out (not heat treated) analyzed as in the top four lines of Table XI. There is some chance that scrap chosen for its content of hardenability residuals was employed in the quenched and tempered parts of this rifle but the chromium content of the cut-out, for which there would seem to be no purpose, would argue that the residuals were accidental. Another example of extraordinarily high phosphorus in a steel with a high carbon level is met in the cut-out, and may be used in an effort to make a free machining steel.

A heavy 7.7-mm. machine gun (Model 92) with a modified Hotchkiss action, made in 1938, had a quenched and tempered breech with only residual alloys; most of the parts, whether normalized or quenched and tempered, were likewise of carbon steel with only residuals. (See the middle part of Table XI.) Four quenched and tempered items were made of tungsten steel (as was one 1942 20-mm. A.P. projectile for the Hotchkiss type gun, as was noted in the third from last line of Table IX). These steels lack the vanadium found in that projectile. The quenched and tempered gas cylinder shows a huge residual tin.

The Jap steels average decidedly higher in sulphur and phosphorus than do the German.

Instead of using carburized nickel-chromium-molybdenum steel for wearing parts, as is the German tendency, the Japs evidently prefer

*Fig. 8 — Japanese 81-Mm. Mortar Shell*

## Table XI — Analyses of Japanese Gun Parts

| DATE | PART | C | P | S | MN | SI | NI | CR | Mo | CU | SN | AL | W |
|------|------|---|---|---|----|----|----|----|----|----|----|----|---|
| | | | | | 7.7-Mm. Arisaka Rifle, Model 99 | | | | | | | | |
| 1939 | Barrel | 0.66 | 0.02 | 0.03 | 0.77 | 0.32 | 0.77 | 0.44 | 0.05 | 0.29 | 0.07 | 0.015 | — |
| 1939 | Breech | 0.80 | 0.03 | 0.04 | 0.80 | 0.31 | 0.22 | 0.54 | 0.03 | 0.23 | 0.06 | 0.005 | — |
| 1939 | Bolt | 0.66 | 0.01 | 0.02 | 0.73 | 0.26 | — | 0.21 | tr. | 0.26 | 0.16 | 0.015 | — |
| 1939 | Cut-out | 0.50 | 0.16 | 0.05 | 0.33 | 0.16 | — | 0.36 | tr. | 0.09 | 0.04 | 0.02 | — |
| | Heavy Machine Gun — 7.7-Mm. Model 92 — With Modified Hotchkiss Action | | | | | | | | | | | | |
| 1938 | Breech | 0.40 | 0.02 | 0.01 | 0.40 | 0.41 | 0.17 | 0.22 | tr. | 0.17 | 0.10 | 0.05 | — |
| 1938 | Barrel | 0.70 | 0.01 | 0.01 | 0.51 | 0.40 | 0.12 | 0.06 | tr. | 0.17 | 0.05 | tr. | 2.31 |
| 1938 | Cartridge feed | 0.68 | 0.03 | 0.01 | 0.55 | 0.30 | 0.12 | 0.15 | 0.01 | 0.20 | 0.05 | 0.015 | 2.06 |
| 1938 | Feed pawl | 0.72 | 0.03 | 0.01 | 0.52 | 0.40 | 0.23 | 0.12 | 0.01 | 0.18 | 0.05 | tr. | 1.98 |
| 1938 | Receiver guide | 0.76 | 0.04 | 0.01 | 0.58 | 0.37 | 0.08 | 0.14 | 0.01 | 0.18 | 0.06 | tr. | 3.41 |
| 1938 | Gas cylinder | 0.51 | 0.05 | 0.05 | 0.58 | 0.14 | 0.03 | 0.02 | tr. | 0.15 | 0.18 | 0.015 | — |
| | Barrels for 7.7-Mm. Vickers-Type Machine Guns for Aircraft | | | | | | | | | | | | |
| 1938 | Barrel | 0.72 | 0.02 | 0.02 | 0.45 | 0.31 | 0.41 | 0.99 | 0.01 | 0.17 | 0.03 | 0.01 | 2.45 |
| 1942 | Barrel | 0.63 | 0.02 | 0.02 | 0.41 | 0.27 | 0.31 | 0.88 | 0.02 | 0.22 | 0.03 | 0.01 | 4.14* |

*Contains also 0.04% vanadium.

hardened tungsten steel. The use of tungsten in barrels is also evidenced in two 7.7-mm. Vickers-type aircraft machine guns, whose breech markings are shown in Fig. 9 (page 308). This may represent a belief that the tungsten steel barrel is sufficiently erosion resistant to justify its use, or merely indicate that, with Chinese tungsten handy, tungsten might as well be used to give the necessary hardenability.

From these examples in Table XI one might think that Jap munition makers avoid the nickel-chromium and nickel-chromium-molybdenum combinations, but these Vickers-type 7.7-mm. guns had a number of such alloy parts. Their vital wearing parts were not carburized and the analyses of the 1938 and 1942 parts were surprisingly close (except for the barrels, as can be seen from an inspection of Table XII).

Here the 0.9% nickel, 0.5% chromium composition was used for four of the five parts, only varied by one steel with lower nickel but added molybdenum (obviously intentional); the other parts are 3¼ to 3½% nickel, 1 to 1½% chromium. One would guess that they analyzed the parts of an early purchased Vickers and adhered to just that analysis for each part in their copies. The tungsten steel barrel may have been their own idea.

**Armor** — Four samples of Jap armor analyzed as shown in the table at the top of the next page. Some cases have been reported of these thin armor plates for pilot protection in Japanese airplanes running 2 to 2½% chromium, ¼ to ½% molybdenum, with only residual nickel, or with over 1% nickel.

The back and head plates, approximately ½ in. thick, from a Type I F "Oscar" Mark II S.E. fighter plane were cross-rolled from a steel of analysis shown in the right hand column.

In any of these the total of alloying elements

## Table XII — Comparison of Steels Used in Japanese Machine Guns of 1938 and 1942 Manufacture

| DATE | PART | C | P | MN | SI | NI | CR | Mo | CU | SN | AL | OTHERS |
|------|------|---|---|----|----|----|----|----|----|----|----|--------|
| 1938 | Barrel | 0.72 | 0.02 | 0.45 | 0.31 | 0.41 | 0.99 | 0.01 | 0.17 | 0.03 | 0.01 | 2.45 W |
| 1942 | Same | 0.63 | 0.02 | 0.41 | 0.27 | 0.31 | 0.88 | 0.02 | 0.22 | 0.03 | 0.01 | 4.14 W 0.04 V |
| 1938 | Bolt steel, bar stock | 0.74 | 0.03 | 0.54 | 0.26 | 0.85 | 0.50 | 0.04 | 0.08 | 0.01 | 0.01 | |
| 1942 | Same | 0.77 | 0.03 | 0.53 | 0.25 | 0.92 | 0.68 | 0.04 | 0.06 | 0.01 | 0.01 | |
| 1938 | Bolt cocking lever | 0.72 | 0.03 | 0.67 | 0.30 | 0.84 | 0.38 | 0.02 | 0.08 | 0.01 | 0.01 | |
| 1942 | Same | 0.79 | 0.03 | 0.55 | 0.40 | 0.85 | 0.56 | 0.02 | 0.07 | 0.01 | 0.01 | |
| 1938 | Bolt ejector, bar stock | 0.37 | — | 0.26 | 0.05 | 3.24 | 1.49 | 0.02 | 0.13 | 0.04 | 0.02 | |
| 1942 | Same | 0.37 | — | 0.55 | 0.26 | 3.44 | 1.05 | 0.02 | 0.09 | 0.03 | tr. | |
| 1938 | Firing pin, bar stock | 0.71 | — | 0.58 | 0.34 | 0.89 | 0.44 | 0.02 | 0.09 | 0.03 | tr. | |
| 1942 | Same | 0.74 | — | 0.55 | 0.37 | 0.96 | 0.49 | 0.02 | 0.10 | 0.02 | 0.01 | |
| 1938 | Bolt handle shaft, forging | 0.63 | 0.01 | 0.42 | 0.42 | 0.55 | 0.41 | 0.15 | 0.17 | 0.05 | 0.01 | |
| 1942 | Same | 0.74 | 0.03 | 0.55 | 0.36 | 0.90 | 0.51 | 0.02 | 0.10 | 0.01 | 0.02 | |

seems high for the thickness of the armor and does not indicate any urge to conserve alloys.

### Analyses of Japanese Armor

| Element | ⅛-In. Body Armor (Recent) | Composite Armor (a) ½-In. Piece | Composite Armor (a) ¾-In. Piece | ½-In. Back & Head Plates |
|---|---|---|---|---|
| Carbon | 0.14% | 0.32 | 0.35 | 0.40 |
| Phosphorus | 0.04 | 0.03 | 0.03 | 0.02 |
| Sulphur | 0.04 | 0.02 | 0.02 | 0.02 |
| Manganese | 0.35 | 0.55 | 0.55 | 1.19 |
| Silicon | 0.21 | 0.22 | 0.23 | 0.19 |
| Nickel | 2.97 | 2.89 | 2.94 | 0.27 |
| Chromium | 0.77 | 0.73 | 0.78 | 1.66 |
| Molybdenum | 0.49 | 0.59 | 0.67 | 0.34 |
| Copper | 0.16 | 0.06 | 0.07 | 0.21 |
| Tin | 0.07 | 0.01 | 0.01 | 0.05 |
| Aluminum | tr. | tr. | tr. | 0.01 |
| Vickers hardness | 400 | 420 | 310 | 605 |

(a) Welded together, weld showing 12% Cr, 8% Ni, 1.5% Mo.

## General Conclusions About Ordnance

Both the Germans and Japs have tended to make unimportant but irregularly shaped gun parts by hogging out from bar stock, when these parts could easily be stamped out from sheet and assembled by copper brazing or spot welding at a saving in man-hours, or where the part could be die-forged to reduce the amount of machining. Later German ordnance practice and designs seem to turn somewhat toward labor saving design, although astonishingly small use is made of free machining steel.

There is some indication that when the Germans resort to a die-forging that would ordinarily call for a succession of dies, they cast a slug roughly to shape, so that one die will suffice. At least, the generally prominent remnants of cast or ingot structure, showing a relatively small reduction by forging, lead to that suspicion, although it may be that this is characteristic of the high chromium compositions used, even with the usual reductions.

Japanese practices generally show still less of an approach to quantity production methods; much hand work is indicated. German workmanship as to finish and dimensional tolerance is consistently good on munitions. Jap workmanship is consistently mediocre although generally adequate for the use intended.

Metallurgically, the heat treatments used and the structures produced are what might be expected with the type of steels used and the intended service of the item. The Germans have introduced new designs and new modifications in guns and projectiles, while the Japs have copied designs of others. The general effectiveness of the munitions usually depends on design rather than materials. The Japs have not been cramped for alloying elements and their metallurgists have not had to exercise much ingenuity, although they have had to get away with an extremely high level of residual tin from scrap.

The use of flame hardening of wearing surfaces on Jap gun parts has been observed on a 20-mm. aircraft machine gun, Type-100 MB, gas operated.

One would guess, particularly from the high molybdenum level in light armor, obviously of quite recent manufacture, and from the high nickel level in some normalized steels, that the Japs have ample stockpiles of alloying elements which permit them to use the more conventional alloy steels.

The German metallurgists have had to devise means of getting the desired properties with the alloying elements at hand. In this task they have done a workmanlike job. Their recent practice centers around steels of high chromium content, and as the supply of chromium gets limited, their style will be a bit cramped, although they are acquainted with various expedients that will serve, but which will require slightly different techniques all along the line and an increased degree of control.
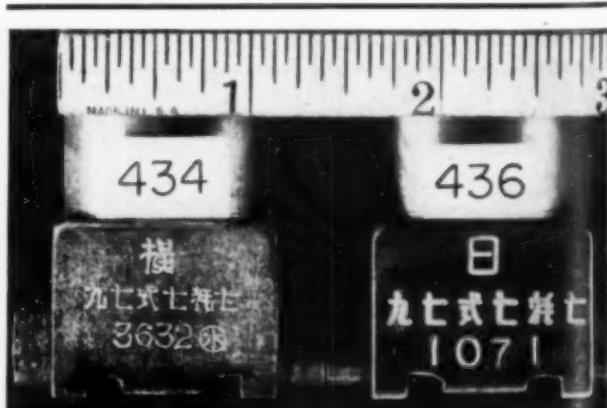


*Fig. 9 — Breech Markings on Barrels of 7.7-Mm. Vickers-Type Machine Guns for Aircraft*

## Studies of Enemy Aircraft

Admittedly, only a partial picture of the enemy metallurgical position is given by a spotty examination of arms and ammunition. The picture is somewhat broadened, although not very much altered, by available information on German and Japanese practices as to aircraft engines.

The highly stressed parts of an aircraft engine are the last to be starved of alloy in the case of a shortage, and the last in which any radical departure will be countenanced from the exact composition, treatment, and fabrication technique of previous parts of satisfactory performance.

The specification of a particular composition and definite properties does not mean that they are best — or even necessary — but rather that they have served in the past and are retained, even in spite of good reason for a change, in order not "to fly to dangers that one knows not of". Even though the metallurgists and the designers know that the properties of an alternate material are such that it will certainly do as well, they find it difficult to overcome the inertia of the non-technical minds who have to give final approval to a change. Hence, the aircraft engine may entirely fail to indicate shortages that are really acute, and may thus be an insensitive indicator, one with a lot of lag. However, if a radical change in the direction of conservation is actually made in such a part, that may be eloquent proof of a real shortage. Or, if a change in manufac-

turing technique is carried through, that is pretty good proof that the new technique has advanced to a dependable stage.

German engines and airframes have been periodically examined by the British and an account published serially in 1942[13] covers German practice of 1941 or earlier. Sutton[22] has reported on the non-ferrous parts. Such examinations are being continued and information from them supplied to our Services. Since this work is quite comprehensive, American metallurgical examinations have not had to be very extensive; special attention, however, is being paid to Jap planes and engines in present American studies.

The British summary notes that alloys were copiously used at the dates represented by the engines reported on, and did not indicate any alloy shortage. Surprise was expressed, in view of the German predilection for a $2\frac{1}{2}\%$ chromium steel without nickel, that the steel had not been used for crankshafts, but a note in the collected report in book form states that later examples have been met where it was used. The steels used in early crankshafts were as shown in Table XIII, page 310. Tensile properties were normal, but a variation was shown in Izod impact. This ran 45 to 75 ft-lb. except for 25 in the B.M.W. rear and 10 to 20 in the nitrided Jumo 211-F. The last mentioned part is made of a steel which is not a regular nitriding composition.

The gudgeon pins of the Jumos and the Bramo Fafnir were carburized, and those of the B.M.W. and the Mercedes Benz nitrided. All the



*Fast and Maneuverable Focke-Wulf-190 Fighter, of Early Model. Studied, flown and maneuvered by technicians at Wright Field to discover possible enemy secrets of design and performance. Photo courtesy Air Technical Service Command*

### Table XIII — Crankshafts From German Aircraft Engines

| Engine and Part | C | Ni | Cr | Mo | V | Heat Treatment |
|---|---|---|---|---|---|---|
| Junkers Jumo, 211-A 211-F | 0.30 | 1.3 to 1.5 | 2.5 | 0.15 to 0.30 | 0.0 to 0.12 | { Not carburized or nitrided. } Nitrided. |
| B.M.W. 132-K, rear half | 0.40 | 0.28 | 1.19 | 0.21 | nil | Not carburized |
| B.M.W. 132-K, front half | 0.16 | 1.92 | 2.14 | 0.25 | nil | Carburized |
| Bramo Fafnir 323-P, rear half | 0.37 | 1.89 | 1.90 | 0.37 | nil | Not carburized |
| Bramo Fafnir 323-P, front half | 0.20 | 1.84 | 2.10 | 0.30 | nil | Carburized |
| Mercedes Benz DB 601-A and 601-N | 0.20 | 1.90 | 1.80 | 0.32 | nil | Carburized |

pins contained 0.20 to 0.25% molybdenum without vanadium. The carburized pins of the Jumo 211-A and of one 211-F contained 2% nickel, 2% chromium, and 0.5% manganese, while those of another 211-F and of the Bramo Fafnir ran 0.26 to 0.37% nickel, 1.15% chromium, 0.90% manganese.

In the Mercedes Benz 601-A the nitrided pins were a regular 1% aluminum, 1.5% chromium, 0.5% molybdenum nitriding steel with 1.75 to 2.0% nickel, but in the 601-N and the B.M.W. the steels ran 2.6 to 2.8% chromium, 0.1 to 0.3% nickel, 0.20 to 0.25% molybdenum, 0.08 to 0.15% vanadium. Similar steels without vanadium were used in the wrist pins of the Bramo Fafnir and the B.M.W., the former being nitrided, the latter cyanided. Carburized heavy-duty gears on all were consistently of 2% chromium, 2% nickel and (except for one with 0.08%) all had 0.25 to 0.35% molybdenum. Vanadium varied from nil to 0.17%. Less heavily loaded carburized gears in the Mercedes Benz were of 1.6% chromium, 1.6% nickel, normal manganese, with 0.35% molydenum, 0.15% vanadium; still less heavily loaded ones in this and the Bramo Fafnir contained 1 to 1.25% chromium, 0.0 to 0.5% nickel, 0.25% molybdenum, no vanadium, with manganese about 0.9%.

In heat treated, uncarburized parts, the propeller hub of the Mercedes Benz 601-A was of 0.32% C, 2% Cr, 2% Ni, 0.4% Mo; the clutch motor body 0.40% C, 1.7% Cr, 0.25% Ni, 0.17% Mo, 0.18% V; the fuel injection pump barrel and plunger of 1% C, 1.4% Cr, trace Ni, no molybdenum or vanadium. (In the Jumo 211-F the pump barrel and plunger were carburized, the barrel being plain carbon steel with low residuals, the plunger 1.1% Cr, 0.35% Ni, 0.20% Mo.)

Connecting rods on the Bramo Fafnir master rod and the Jumos were 0.30 to 0.35% carbon, 1.5 to 2% nickel, 1.9 to 2.5% chromium, 0.25 to 0.35% molybdenum, without vanadium. The earlier Jumos had 0.14 to 0.17% molybdenum with 0 to 0.20% vanadium on later ones. The Bramo Fafnir master rod was nitrided. The Bramo Fafnir auxiliary rod, as well as the B.M.W. rods, and the Mercedes Benz rods were of steel containing 0.30 to 0.40% carbon, 1.0 to 1.25% chromium, 0.05 to 0.55% nickel, 0.15 to 0.25% molybdenum, and no vanadium.

The bolts and nuts in the Mercedes Benz and in an earlier Jumo were 2% Cr, 2% Ni, 0.25% Mo; in a later one, 2.5% Cr, 0.20% Mo, 0.25% V, and only residual nickel. A stud from the big end of the double rod of the early Jumo had 3.5% Ni, 1% Cr, and in the Mercedes Benz the big end bolts, carburized in places, were 4.3% Ni, 1% Cr, 0.09% Mo, and no vanadium.

The cylinder liners were all of 0.40 to 0.50% C, 1.5% Cr steel, with only residual nickel (0.03 to 0.27%), and molybdenum nil to 0.13%. The cylinder bolts on the early Jumos were 2% Ni, 2% Cr, with Mo; in a later one 1% chromium, with molybdenum, heat treated to the same strength as the former.

Engine mount tubing from B.M.W. and Bramo Fafnir was the conventional 1% chromium, 0.25% molybdenum.

Wing root fittings of the ME-110 were of either the 2½% chromium steel (or 1.25% Cr) always with 0.15 to 0.40% molybdenum. Spars of the Junkers 88 were 2.25% Cr, 2.25% Ni, 0.25% Mo in an early one; 2.25% Cr, 0.25% Mo with only 0.3% Ni in a later one. Both had 0.15 to 0.25% vanadium.

Steel in the undercarriage axles contained 1% chromium and 0.25% molybdenum, without vanadium and with only residual nickel. The

axle of the Junkers was a drawn tube; that of the Messerschmitt a casting. The composition noted was used in a large number of other undercarriage parts, with a few exceptions which used a 2.5% chromium, 0.25% molybdenum, 0.25% vanadium steel.

The jaws of the mine layer release from one plane were of air hardening steel: 0.40% C, 4.40% Ni, 1.45% Cr.

All the aircraft steels appeared to be basic electric, very clean, and very low in sulphur and phosphorus.

On consideration of the duty of the various parts, the indications were that chromium plus a heavy dose of molybdenum were the mainstay alloying elements, with vanadium used when available, in which case the molybdenum was cut down. Nickel was at first used to get deep hard-

with 3.5 to 4.5% Ni, 1.5% Cr, 0.35% Mo (with some shafts having less molybdenum but with 0.5 to 1.0% tungsten and 0.5% cobalt).

As background, also, might be considered a recent German article by Krish,[16] following up earlier articles by Pomp and Krish in which chromium-molybdenum was discussed in 1938. In 1942, and especially in 1944, emphasis was put on molybdenum-free steels of the chromium-manganese-vanadium type, ranging up to 2½% Cr, 2% Mn and 0.20% V, especially the chromium-manganese combination. Schinn and Tinti[17] also point out that Germany needs to conserve both molybdenum and chromium. In contrast to their earlier general and lavish use of molybdenum, this statement sounds as though the Germans were readying themselves to get along with less molybdenum, to utilize vanadium

**Table XIV — Range of Analyses of German Alloy Steels in Engine Auxiliaries**

| Auxiliary | Number | Ni Range | Cr Range | Mo Range | V Range | Cu Range | Sn Range | Mn Range |
|---|---|---|---|---|---|---|---|---|
| Starter | 3 parts | 0.04 to 0.21 | 0.97 to 1.18 | 0.20 to 0.30 (a) | Nil | 0.23 to 0.29 | 0.01 to 0.04 | |
| | 7 parts | 0.09 to 0.17 | 1.18 to 1.46 | 0.01 to 0.05 (b) | Nil | 0.12 to 0.29 | 0.04 to 0.07 | |
| | 11 parts | 0.08 to 0.20 | 0.99 to 1.28 | 0.03 to 0.08 | Nil | 0.11 to 0.26 | 0.02 to 0.06 | 1.05 to 1.33 |
| | 4 parts | 0.13 to 0.23 | 1.04 to 1.08 | 0.04 to 0.11 | 0.01 to 0.05 | 0.11 to 0.17 | 0.02 to 0.05 | 1.10 to 1.22 |
| Main oil pump | 5 parts | 0.08 to 0.17 | 0.98 to 1.23 | 0.01 to 0.10 | | 0.14 to 0.27 | 0.02 to 0.04 | 0.61 to 0.71 |
| (c) | 2 carburized | 0.08 to 0.17 | 1.20 to 1.25 | 0.01 to 0.07 | | 0.15 to 0.25 | 0.03 to 0.04 | 1.27 to 1.45 |
| | 1 carburized | 0.29 | 2.40 | 0.08 | 0.21 | 0.20 | 0.04 | |
| Fuel pump (c) | | 0.01 to 0.08 | 0.96 to 1.42 | Nil | | 0.26 to 0.27 | 0.03 to 0.04 | 1.31 to 1.46 |
| Solenoid cam & camshaft | 2 parts | 0.01 to 0.08 | 0.96 to 1.42 | Nil | | 0.26 to 0.27 | 0.03 to 0.04 | 1.31 to 1.46 |

(a) Added.     (b) Residual.     (c) From B.M.W. 801-C engine.

ening in large sections, or when especially severe duty was involved, but later the chromium tended to be high with no nickel addition and only a little residual. Silicon and manganese were generally at normal levels, except that in certain gears was the latter raised to an alloying level.

There was a tendency to nitride steels that did not contain the high aluminum of the ordinary steel intended for nitriding. Design to minimize stress concentration, machine shop work, heat treatment practice, and inspection were all consistently excellent.

This British summary affords a background against which to place the examinations made in the United States of later engines and other aircraft components of German make, as well as those produced by the Japs. An exhaustive U. S. study[14] of an early Junkers 211-B engine brought out the lavish use of alloys, especially of the 2% Ni, 2% Cr type. A recent account[26] discusses a German electric propeller. A similar study[15] of an early Jap Mitsubishi Kinsei engine brought out the widespread use of an "all purpose" steel

instead, as though they had a more assured supply of it, and probably to extend the use of steel of the 1% Cr, 1 to 1.25% Mn type, with or without vanadium, where the 2.5% Cr, 0.5% Mo type had previously been used.

## Type of Scrap Used for Steel in Minor Parts

Another point of interest is the residual metals, since this gives a clue as to the scrap being used. The British reports showed that around 0.10% Cu, and 0.02 to 0.20% Ni were being met in so called "plain carbon" steels at the date of manufacture of the steels examined. In the alloy steels not intentionally alloyed with nickel, nickel might range anywhere from 0.02 to 0.40%, with a tendency to be in the 0.10 to 0.30% range. Little information on the chromium or molybdenum content of scrap can be gotten from the British data, since so many of the steels were intentionally alloyed with both. Tin was not determined in the analyses in the British report.

Before turning to the highly stressed, very important parts of German engines, we may examine some data on auxiliary equipment, in which the steels have relatively less severe duty, for indications on the scrap situation and the alloying trend. For example, in an airplane engine starter, undated but probably fairly recent, of some 35 steel parts selected for examination no free machining steels were found, and a dozen "plain carbon steels" ranged from 0.03 to 0.07% Ni, 0.03 to 0.15% Cr, 0.04 to 0.37% Cu, 0.01 to 0.05% Sn. Molybdenum was generally absent save for traces, with 0.03% the highest reported. The alloyed steels on these auxiliaries fell within the ranges shown in Table XIV, p. 311.

Of the parts examined in the main oil sump pump from a B.M.W. 801-C engine, four were of plain carbon steel with 0.02 to 0.16% Ni, 0.02 to 0.22% Cr, 0 to 0.01% Mo, 0.02 to 0.10% Cu, a trace to 0.07% Sn. Of the alloy steel parts one had 1.10% Mn and nothing else save low residuals; five others and three carburized parts are shown in Table XIV.

In the fuel pump of the B.M.W. 801-C, the only manganese-chromium steel was in the solenoid cam and cam shaft, with high C; its range of analysis is shown in Table XIV. The camshaft plate was 2.35% Cr, with 0.16% Ni, 0.18% Mo, 0.18% V, 0.19% Cu, 0.06% Sn. The cam plate was 1.82% C, 0.12% Cr, 0.52% V, no Mo,

0.15% Ni, 0.19% Cu, 0.08% Sn. The timing shaft and tappet guide were 1.04% C, 0.97% Cr, 0.23 to 0.24% Mo, with low residuals.

Some ten of the other alloy steel parts contained 1.20 to 1.43% Cr, with molybdenum from a trace to 0.05%, nickel 0.06 to 0.14%, copper 0.12 to 0.21%, tin mostly 0.01 to 0.04%, except for two cases where it ran up to the astonishing figure of 0.20%. One plain carbon steel had residuals of 0.26% nickel, 0.35% chromium, 0.06% molybdenum, 0.20% copper, 0.01% tin, both the nickel and chromium being at an unusually high level for a non-alloyed steel.

One carburized bushing in a German Bosch fuel injector carried 0.24% Cr, 0.09% Ni, 0.07% Mo. Such cases indicate that recent chromium-alloyed scrap is sometimes mixed with plain carbon scrap, because under normal conditions ordinary scrap would be higher in nickel than in chromium. The liner and the guide barrel were of 1.2% chromium steel, with very low residual nickel and 0.05 to 0.06% molybdenum.

The counterweight on the crankshaft of the Mercedes Benz DB-60 engine was of plain carbon steel, and carried 0.35% Cr, 0.20% Ni, 0.11% Cu, 0.02% Mo and 0.01% Sn residuals. The pins had 0.24% Cr, 0.16% Ni, 0.08% Cu, 0.03% Mo, 0.01% Sn. Cast irons examined also carried higher residual chromium than nickel, but both were low.



*Fig. 10 — Excellent Workmanship on Articulated Connecting Rod From German B.M.W. 801-D 2 Aircraft Engine*

*Fig. 11 — Cast, or Only Slightly Forged Crank-shaft of Nickel-Chromium Steel, 53 In. Long, for German DB 601-E Aircraft Engine*

## Vital Engine Parts and Valves

More vital parts of German engines are as shown in Table XV. The crankshaft from a B.M.W. 801-D/2 (first line) was forged and its bearing throws carburized. The articulated rod is shown in Fig. 10. The rods were highly polished and the numbers and inspector's stamp were not pressed in with steel stamps, but were stamped in ink or lightly acid etched to avoid stress concentration and favor fatigue life.

That the master rod was nitrided all over, even though not a "nitriding" steel, is probably also to add to fatigue life. The British report stated that the master rod in the Bramo Fafnir was nitrided all over.

The use of nickel, chromium, molybdenum and vanadium, all together, in the front cam does not argue any extreme shortage at the date of manufacture.

The engine mounting ring of this engine, in a Focke-Wulf 190, was of interest. The British report showed the conventional chromium-molybdenum tubing in German engine mounts, but this one analyzed: C 0.17%, P 0.01%, S 0.02%, Si 0.54%, Mn 3.00%, Ni 0.06%, Cr 0.06%, Mo 0.02%, Cu 0.21%, Sn 0.07%, Al 0.015%. The mechanical properties were:

| SPECIMEN | TENSILE STRENGTH | ELONGATION |
|---|---|---|
| No. 1 | 90,000 psi. | 15% |
| 2 | 90,000 | 16 |
| 3 | 89,000 | 17 |
| 4 | 103,000 | 16 |
| 5 | 110,000 | 15 |

The evidence as to scarcity of manganese is conflicting. Ordinarily the 2.5% Cr, 0.5% Mo steel predominates over the 1% Cr, 1.25% Mn type, yet in this engine mount 3% Mn takes the place of the usual 1% Cr, 0.25% Mo tubing. High manganese, high sulphur steel (free machining) is relatively scarce in parts where its use would be logical, yet there is no strikingly consistent sign of skimping much on manganese content of carbon and alloy steels in which it is not used as a strengthening alloy. In view of the generally low sulphur, the manganese could often have been reduced.

Table XV (page 314) also contains analyses of parts from a Mercedes Benz DB 601-E engine. This crankshaft, shown in Fig. 11, was cast. Its dendritic structure showed no clear evidence of any forging, even in the end lug through which the counterweights are pinned and which, in a forging, would have shown much deformation. The microstructure was coarser where risers had been attached, and the sulphide inclusions were the typical rounded ones of a steel casting, not the elongated ones of a good forging. This was a
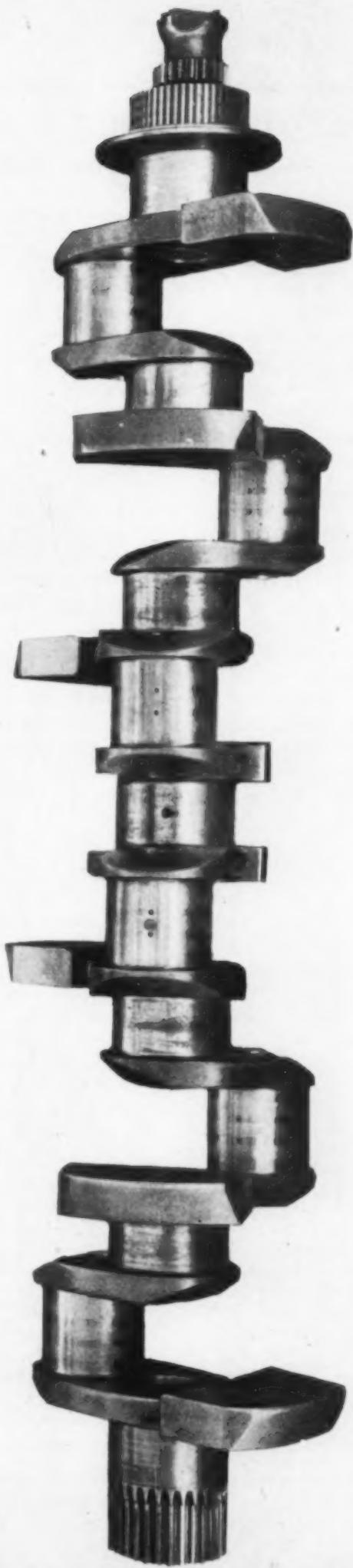
beautiful casting. Charpy impact specimens from it gave 35 to 40 ft-lb.

In the British report, comment on early crankshafts was made that the early shafts had normal grain flow for forgings, but that the dendritic structures indicated the use of a small ingot, and relatively little deformation. More machining (that is to say, forging more oversize than would be customary) was also postulated. It was noted that transverse properties were similar to longitudinal ones.

Whether the cast shaft was an experimental one, or whether the customary method is to cast the shaft somewhat oversize and give it only a slight amount of forging in one or two dies rather than to break it down from a billet in a succession of dies, or whether the forging equipment was out of commission when this shaft was made and hence the unforged casting was used, is anybody's guess.

The British report comments on the use of very high quality steel castings in important under-carriage parts on the Junkers 88 and Messerschmitt 109, and the assisted take-off hook on the Heinkel III, in which 1% Cr, 0.25% Mo steel was consistently used.

## Engine Valves

In four quite different types of German aircraft spark plugs, of the steel body shells — which one would expect always to be made from free machining steel — only one was so made; neither was the shell of a Jap spark plug. The usual nickel-base electrodes with 1.5% manganese were used in the German plugs, except for the center electrode of one, which was a 28% chromi[um] steel. The Jap ground electrode had only 1[.5] manganese, the center electrode was 18% Ni, [(] Cr with a nickel tip. Both the German and [Jap] nickel tips sometimes showed over 1% cob[alt]

Sutton[23] reports that the Germans often u[se] an alloy of 70% copper, 30% silver for electr[ic] fuse wire.

German aircraft valves show the usual [use] chrome for the intake, and an approximation [of] the usual T.P.A. composition save for a bit low[er] nickel and quite a bit higher silicon in the exha[ust] valves. 1% copper was found in one valve; p[er]haps Monel scrap provided part of the nic[kel.] The facing is the conventional stellite. [The] welded-on head (Fig. 12) of an exhaust valve [of] the B.M.W. 801-D engine is a deviation fr[om] usual practice, but was noted for this engine [in] the British report. The methods of inserting t[he] sodium filling in the exhaust valves vary. [The] wear resisting tip is welded on in the Germ[an] valves.

Japanese intake valves from a Sakae rad[ial] engine were conventional silcrome with ch[ro]mium and molybdenum on the high side; [the] exhaust valves were conventional T.P.A., w[ith] high silicon. The seat facing was conventi[onal] stellite. On a type 1000, 1450-h.p. radial eng[ine] made in 1942 and taken from a Sally Mitsubi[shi] plane, the intake valve was 7% Cr, 5.5% [Si] instead of the usual silchrome, and the exha[ust] (instead of being the usual 14% Ni, 14% Cr, [2%] W austenitic T.P.A. steel) had 11% Cr, 2.25% [W,] 2% Mo, with only 0.3% Ni, thus verging m[ore] toward the composition for the usual intake v[alve] than the usual exhaust valve.

#### Table XV — Analyses of Steels in Vital Engine Parts

| Part | C | P | S | Si | Mn | Ni | Cr | V | Mo | Cu | Sn | Al |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parts From a B.M.W. 801-D/2 Engine | | | | | | | | | | | | |
| Crankshaft | 0.18 | 0.01 | 0.01 | 0.24 | 0.50 | 1.70 | 1.62 | tr. | 0.14 | 0.20 | 0.04 | tr. |
| Counterweight | 0.40 | 0.02 | 0.03 | 0.34 | 0.60 | 0.15 | 0.19 | tr. | 0.05 | 0.15 | 0.03 | 0.01 |
| Articulated rod | 0.42 | 0.02 | 0.01 | 0.27 | 0.57 | 0.29 | 1.03 | tr. | 0.20 | 0.13 | 0.02 | 0.01 |
| Nitrided master rod | 0.30 | 0.01 | 0.01 | 0.22 | 0.58 | 0.21 | 2.25 | 0.22 | 0.36 | 0.10 | 0.04 | 0.02 |
| Front cam, carburized | 0.34 | 0.01 | 0.01 | 0.24 | 0.37 | 1.90 | 1.56 | 0.20 | 0.26 | 0.18 | 0.04 | 0.01 |
| Drive gear shaft, carburized | 0.29 | 0.01 | 0.01 | 0.23 | 0.70 | 0.23 | 2.20 | 0.16 | 0.33 | 0.13 | 0.04 | 0.02 |
| Cylinder barrel, normalized | 0.40 | 0.01 | 0.02 | 0.23 | 0.53 | 0.09 | 1.53 | tr. | 0.03 | 0.13 | 0.04 | 0.01 |
| Parts From a Mercedes Benz DB 601-E Engine | | | | | | | | | | | | |
| Crankshaft (throws carburized) | 0.19 | 0.01 | 0.01 | 0.21 | 0.52 | 1.61 | 1.78 | — | 0.15 | 0.15 | 0.03 | tr. |
| Connecting rod fork | 0.41 | 0.02 | 0.02 | 0.24 | 0.79 | 0.19 | 1.19 | — | 0.20 | 0.25 | 0.03 | tr. |
| Connecting rod blade | 0.32 | 0.02 | 0.01 | 0.28 | 0.57 | 0.63 | 1.20 | — | 0.21 | 0.18 | 0.03 | tr. |
| Connecting rod bearing | — | — | — | 0.28 | 0.33 | 0.04 | 1.42 | — | tr. | 0.02 | 0.02 | tr. |
| Wrist pin | 0.29 | 0.02 | 0.01 | 0.23 | 0.63 | 0.25 | 2.23 | 0.17 | 0.20 | 0.05 | 0.05 | 0.02 |

Variations from normal practice were sometimes met. Heads of the intake valves have been chromium plated. On the exhaust valves, some had the stems forged nearly shut after sodium filling and closure made by welding the stellite tip; and some were plugged, or forged nearly shut and closure made by flash welding a toolsteel tip.



*Fig. 13 — Articulated Connecting Rod From a Jap Sakae-21, Highly Polished But With Deeply Stenciled Numbers; Full Size*

Some ingenuity was thus shown in fabrication methods.

**Jap Engine Parts —** In the examination of a Jap Sakae-21 engine several examples were analyzed and the results tabulated in the top part of Table XVI. The connecting rod (Fig. 13) is interesting in that a vast amount of pains was taken to polish it to a mirror finish, but numbers were deeply stamped with steel stencils; thus, a great lack of understanding of the effects of stress concentration was shown. This is in marked contrast with the avoidance of stamped numbers in German practice.

The engine mount was made of a number of different heats of steel all aimed to be the conventional S.A.E. 4130, and in all of which the residuals were disregarded. The level of residuals in Jap scrap may be seen from the analyses of parts from a Sakae-12 engine in the lower portion of Table XVI (page 316).

The general high level of tin will be noted in these analyses, even in the high chromium steel of Item D. There is no obvious reason for the high aluminum in the steel for Item A, nor for the molybdenum in Item B. The residual nickel and tin in the roller bearing race, Item H, shows the use of miscellaneous scrap in this important part. Items J and L show nickel-chromium-molybdenum steel of high nickel content in parts not large enough to need that degree of hardenability. Items M, N, and O show high nickel and variable chromium in the carburized steels.



*Fig. 12 — Welded-In Head in Exhaust Valve for German B.M.W. 801-D 2 Aircraft Engine. Sectioned on center; full size view*
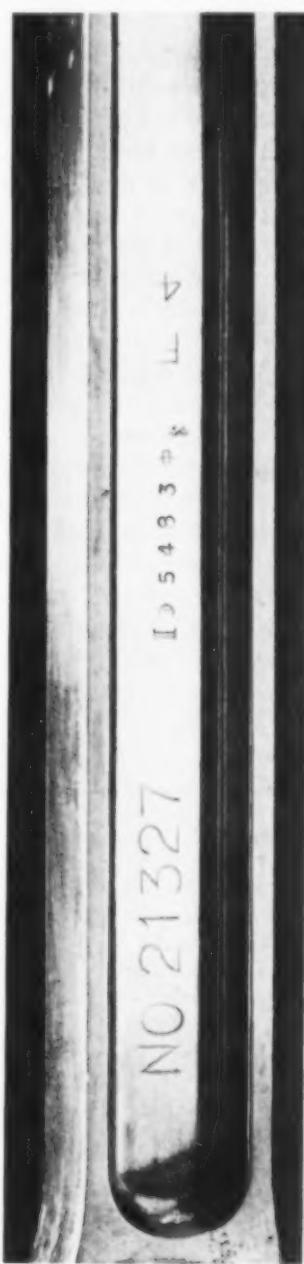
Several Jap ball bearings, all of the conventional composition used by the Germans and all other countries, but with improper heat treatment, have been found. When quenching and tempering it appears as though the Japs were heating small articles, *en masse* and assuming that each piece is uniformly heated, and that their inspection is inadequate to pick out pieces not properly treated. However, outside of certain glaring examples, such as the connecting rod with the stamped numbers and the ball bearings, their workmanship is generally adequate, although much more hand work is done than in more industrialized countries.

There is evidence that the Japs are still back in the era of high nickel alloy steels. Their alloy steel specifications reflect those used in other countries prior to the war need for conservation. This lack of progress may come from making a complete copy, including the exact composition of each part, of the first example they acquired.

For example, a magneto copied from an American design turned out, piece by piece except for the magnet, to be just the same compositions as were used in early American models, as well as exact copies geometrically.

In respect to steels, the following conclusions seem in accord with the scattered available data.

There is no sign that the Japs have tried to conserve alloys in their alloy steel; they are lavish in use of nickel and disregard the nickel content of their scrap, which is very variable but averages much higher than in American scrap. The Jap scrap runs consistently high in tin, even as used for highly alloyed heat treated parts. They adhere to what might be termed classical, old-time specifications and probably are in much less flexible condition than the Germans to substitute one steel for another in case of shortage of a particular alloy. They do not make as much use of molybdenum as the Germans do — nor when they use it, do they run it as high. The

### Table XVI — Analyses of Steels in Parts of Japanese Aircraft and Engines

| Name | C | P | S | Mn | Si | Ni | Cr | Mo | Cu | Sn | Al | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Parts | From | Sakae-21 | Engine | | | | | | |
| Nitrided cylinder barrel | 0.47 | 0.014 | 0.027 | 0.40 | 0.29 | 0.48 | 1.43 | 0.20 | 0.25 | 0.07 | 0.90 | |
| Push rod ends | — | 0.010 | 0.024 | 0.31 | 0.27 | 0.15 | 0.06 | 0.018 | 0.27 | 0.14 | 0.03 | |
| Motor mount | 0.32 | 0.014 | 0.021 | 0.65 | 0.45 | 0.10 | 1.10 | 0.30 | 0.21 | 0.01 | 0.005 | |
| Front crankshaft | 0.18 | 0.021 | 0.035 | 0.57 | 0.21 | 4.15 | 1.68 | 0.17 | 0.34 | 0.05 | 0.030 | |
| Piston pin | 0.11 | 0.014 | 0.023 | 0.57 | 0.17 | 4.50 | 0.86 | 0.12 | 0.19 | 0.04 | 0.005 | |
| Articulated rod | 0.25 | 0.012 | 0.012 | 0.55 | 0.24 | 3.38 | 1.39 | 0.40 | 0.26 | 0.09 | 0.005 | |
| Impeller shaft | 0.13 | 0.013 | 0.023 | 0.54 | 0.19 | 4.65 | 0.42 | 0.08 | 0.20 | 0.03 | 0.03 | |
| | | | Parts | From | Sakae-12 | and | Other | Engines | | | | |
| A. Clamp from oil tank | 0.15 | 0.04 | 0.04 | 0.31 | 0.16 | 0.07 | 0.07 | nil | 0.22 | 0.13 | 0.16 | Cold rolled bar |
| B. Ring washer from oil tank | 0.19 | 0.01 | 0.01 | 0.46 | 0.16 | 0.06 | 0.02 | 0.29 | 0.20 | 0.10 | 0.01 | Not heat treated |
| C. Bolt from oil tank | 0.48 | 0.02 | 0.02 | 0.41 | 0.44 | 0.08 | 0.08 | 0.01 | 0.21 | 0.09 | 0.01 | |
| D. Throttle shaft from four-barrel carburetor | 0.26 | 0.03 | 0.02 | 0.22 | — | 1.59 | 13.60 | 0.02 | 0.20 | 0.12 | 0.01 | (0.04% V) Heat treated |
| E. Connector shaft from above | 0.27 | 0.01 | 0.04 | 0.58 | 0.58 | 2.91 | 0.78 | 0.01 | 0.17 | 0.04 | tr. | Heat treated |
| F. Carburized ring surrounding outer race of self aligning bearing | — | 0.01 | 0.01 | 0.52 | 0.18 | 4.70 | 0.38 | 0.07 | 0.16 | 0.02 | tr. | |
| G. Outer race from above | 1.04 | 0.03 | 0.02 | 0.67 | 0.37 | 0.07 | 1.39 | tr. | 0.18 | 0.10 | 0.02 | |
| H. Inner race from above | 1.00 | 0.03 | 0.02 | 0.24 | 0.37 | 0.28 | 1.36 | 0.02 | 0.20 | 0.10 | 0.02 | |
| I. Long studs in gear oil pump | 0.33 | 0.01 | 0.03 | 0.47 | 0.38 | 0.05 | tr. | tr. | 0.19 | 0.09 | tr. | |
| J. Short studs from above | 0.29 | 0.01 | — | 0.45 | 0.24 | 3.13 | 1.27 | 0.09 | 0.22 | 0.05 | 0.01 | Heat treated |
| K. Check valve | 0.31 | 0.01 | — | 0.54 | 0.33 | 0.07 | 0.07 | 0.02 | 0.09 | tr. | 0.01 | (0.08% W) Cold rolled bar |
| L. Another check valve | 0.33 | 0.03 | — | 0.55 | 0.23 | 2.80 | 1.01 | 0.10 | 0.20 | 0.09 | 0.02 | Heat treated |
| M. Long gear shaft | 0.20 | 0.04 | — | 0.46 | 0.23 | 4.69 | 0.39 | 0.04 | 0.19 | 0.04 | 0.02 | Carburized |
| N. Shorter gear shaft | 0.17 | 0.02 | 0.02 | 0.52 | 0.18 | 3.11 | 0.69 | 0.17 | 0.16 | 0.05 | 0.01 | Carburized |
| O. Gear | 0.11 | 0.01 | 0.03 | 0.36 | 0.31 | 4.43 | 0.22 | 0.04 | 0.21 | 0.04 | 0.01 | Carburized |

general German practice of using very high chromium in constructional, heat treated steels is not commonly followed in Japan. Conversely, the Jap use of aluminum in such steels is not followed in Germany.

## Non-Ferrous Alloys

The sticking to conventional alloys extends through the copper-base and aluminum-base alloys. Seldom is a composition used by the Japs that is not covered by an old German, English, or American specification. There seems to be a general tendency to worship strength, without much regard to the ease of machining, or to the increased propensity toward notch propagation, or to other factors which lead engineers in other countries to compromise on strength in order to gain machinability or toughness.

Their bronze bearings are harder than comparable ones in other countries.

They have used — though apparently only to a small extent — a high strength heat treated wrought aluminum alloy containing zinc, based on the 20-year-old German "Constructal" family of alloys, despite known difficulties in production and fabrication, and the drawbacks of stress corrosion and a lack of toughness under certain stress conditions. Sutton[24] reports this alloy, in an extruded spar of the O.S.S.F. "Zeke", to con-

tain 2.13% Cu, 0.28% Si, 0.55% Mn, 1.12% Mg, 0.28% Fe, 7.90% Zn, and to show 64,000 to 69,500 psi. tensile strength, 62,000 to 67,000 psi. yield at 0.2% elongation, 13% elongation in 2 in. Its yield strength is appreciably higher than that of the 4% Cu, 1.1% Mn, 1.1% Mg extruded spars in five different German planes examined by Sutton. A 10% silicon alloy containing nearly 0.50% cobalt has also been found in Japanese equipment. The use of cobalt was obviously adopted from European practice.

As is evidenced by recent articles by Brenner[18] and by Petri, Siebel, and Voss Kühle,[19] the Germans are discussing alloys of this type, but are putting emphasis on zinc as a substitute for copper in the strong aluminum alloys as a conservation measure rather than for added physical properties.

Both Japs and Germans make some use of the clad aluminum alloys in which the corrosion-resistant surface overlying the strong core is not always pure aluminum, as in Alclad, but is sometimes alloyed to give a trifle more strength. The Japs seem more willing to use unclad alloys and to omit anodizing than do engineers in other countries.

Outside of the permanent magnet alloys, few metallurgical innovations have come out of Japan in the past and, so far, there is little sign that war activity has led them to new ones. They seem
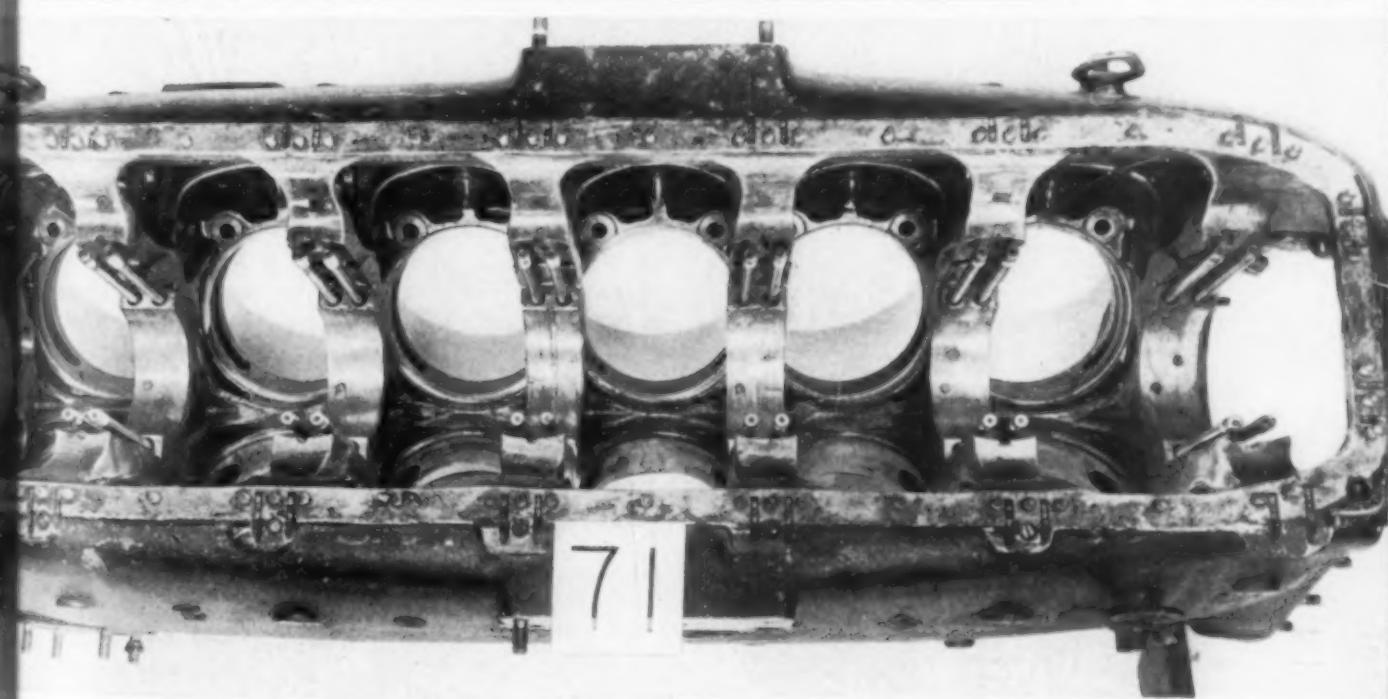


*Fig. 14 — Crankcase Cast From Modified Aluminum-Silicon Alloy (German DB 601-E Aircraft Engine)*

to have stockpiled copper, nickel and other alloying metals to such a degree that they have felt able to use conventional, lavishly alloyed steels and non-ferrous alloys without making the slightest effort toward conservation and substitution in armament and aircraft. Indeed, in one Jap engine, the crankshaft counterweights were of forged manganese bronze!

Germans, on the contrary, are exercising extreme conservation of copper (for example, in certain spark plugs the customary copper gasket is replaced by soft iron) and marked economy in use of nickel, although they still adhere to the high nickel "Krupp" analyses for some important carburized parts, and still use a fair amount of

nickel for depth hardening in certain guns. B they think twice before using a gram of nick if it can reasonably be avoided. Cutting off the last pound of their nickel imports might cram their style quite a bit. They are obviously desi ous of conserving molybdenum, but not so lo ago they must still have had a large stockpil since they have often used 0.50% of this eleme in an alloy when American practice would co sider 0.25% ample.

The Germans are quite willing to forget of specifications and judge a material on propertie and performance rather than chemical compos tion. Their high strength, copper-base alloys of the manganese bronze and aluminum bron types are hybrids, concocte according to what they ha available to put into them the moment, and do not me anybody's formal specific tions as to composition, h do have entirely adequa properties.

Some of their innovation are a bit shocking to an o line materials engineer. Di regard of brittleness conventional tests in the ca of powdered iron drivin bands and cast tungsten ca bide bullet cores — when ser ice tests show the material usable — has already bee commented upon.

Other deviations fro usual practice are in aircra engine camshaft bearing where instead of the usu copper-base alloys, cast iro was used in a piston pin slee bearing; also in an alloy 6.5% Al, 2.5% Sn, 0.25% M 0.15% Si, balance magnesiu which was used for the cam shaft bearing in a Merced Benz DB 601-E; and in a mo surprising alloy of alumina with 5% iron which was use in the air clutch bearing an the camshaft bearing of th Jumo 211-B German engin (one forging made of this allo



*Fig. 15 — Cylinder Head and Barrel for German B.M.W. 801-D/2 Aircraft Engine, Used As-Cast From Aluminum-Magnesium-Silicon Alloy*

also used for the fuel injection pump case). The bearing properties of these light alloys are inferior by usual tests, and their bearing applications are definitely limited; but whether to save copper or to save a kilogram of weight, the substitution was made, evidently in the belief that with proper lubrication camshaft bearing service can be had from highly unconventional bearings. The Japanese, in copying the German DB-601 engine (Japanese Aichi), maintain the magnesium camshaft bearing.

Another case of German deviation from the ordinary was in the Mercedes Benz DB 601-E crankcase, shown in Fig. 14. This was a wonderfully sound and perfect casting, representing the highest state of the aluminum founder's art. It was made of an aluminum-silicon alloy with a carefully controlled addition of magnesium, and modified with sodium. The analysis was 9.5% Si, 0.20% Mg, 0.40% Fe, 0.03% Na, balance aluminum. Specimens 0.505 in. diameter cut from the casting showed 38,000 psi. tensile, nearly 32,000 psi. yield, 3% elongation, 4½% reduction of area, and 94 Vickers Brinell. This alloy and its heat treatment have been described by Sachs.[20]

The freedom from cracking in this very complicated casting, the evident easy castability of the alloy, combined with the very good properties of the actual casting, as well as its freedom from porosity, shrinks, and other foundry troubles, make this an outstanding example. The Japanese in their copy of the DB 601 did not do so well and produced a casting with much porosity. Good aluminum foundry practice is usual in German products. The cylinder head in Fig. 15 for the B.M.W. 801-D/2 engine cast from 5% Mg, 1% Si, balance aluminum alloy, was notably free from porosity or casting defects. This was used in the as-cast condition.

A somewhat rare alloy was met in the B.M.W. 801-D/2 engine of the Focke-Wulf 190 in the front cam follower guide, a forging weighing about 8 lb., and shown in Fig. 16. This contained 5.5% cerium, 1.5% manganese, bal-

ance magnesium. Such alloys are known to hold their strength at elevated temperatures. This forging had a Brinell hardness of about 80 at room temperature, and held up to about 45 Brinell at 400° F., at which other magnesium alloys would have become too soft and weak. Sutton[24] found the aluminum supercharger impeller of a B.M.W. 801-A to be alloyed with 1.5% manganese and 4.5% cerium, and it had the relatively poor properties of 37,000-psi. tensile strength, 3 to 8% elongation (the duralumin impeller of the D13 601-A gave 60,000-psi. tensile strength). He suggests that the magnesium-manganese-cerium alloy was used because of its ease of forging.

Schmidt[21] comments that the compositions of German magnesium alloys are quite similar to those of American alloys, but that in the case of sand and die castings, usually heat treated here, the Germans normally omit heat treatment. Sutton[24] comments that some castings are used as cast, others are heat treated. Such observation raises the question whether heat treatment really makes the castings more serviceable and whether



Fig. 16 — Cam Follower Guide on B.M.W. 801-D/2 Engine, 16.5 In. Diameter, Weighing 8 Lb., and Forged of Magnesium Alloy Containing 1.5% Manganese and 5.5% Cerium

we, too, might in some cases do without heat treatment and so avoid one rather expensive processing operation.

So far, the real leads from Japanese metallurgical practice have been very few, and their value doubtful. The German metallurgical innovations are more numerous, and, while perhaps more often dictated by scarcity than by a search for something of better engineering effectiveness, they deserve careful consideration.

While the Germans do not appear to have grasped or utilized to the degree attained in America the concept that hardenability is the vital thing in heat treatment and that the particular composition by which hardenability attained is non-vital, their large scale use of high chromium steel and their almost comp avoidance of nickel, do materially strength that concept.

Even though innovations applicable to A ican metallurgy are rarely found in such stu as have been described, it seems worth while be on the watch for them from the point of vi of engineering, as well as to glean such stra as may help to indicate the path to the m effective strategic bombing and other means cutting off supplies of alloying elements wh loss would hamper the enemy.

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# PERSONALS

W. K. HUNT ✪ has left the Reynolds Metals Co. in Louisville, and is now employed as research metallurgist with Deere & Co., Moline, Ill.

ALBERT M. TAYLOR ✪ has been appointed superintendent of the two plants of Arcos Corp., Philadelphia.

LT. COL. M. L. BEGEMAN ✪ has been on active duty in the Ordnance Department at the Southwestern Proving Ground at Hope, Ark., and has now returned to University of Texas to resume his former duties as professor of mechanical engineering and superintendent of the engineering shop laboratories.

E. E. MUELLER ✪, formerly with the Carpenter Steel Co., is now associated with the Ziv Steel & Wire Co.'s sales department, Chicago.

Rustless Iron & Steel Corp. Baltimore announces that the activities of its metallurgical research and chemical departments has expanded so much in the last years as to warrant its organization as an independent research division. It will continue under A. L. FEILD ✪ as director, with responsibility for details of the work divided between CARL A. ZAPFFE (who joined the staff from Battelle Memorial Institute over a year ago) and F. KENNETH BLOOM ✪, for many years senior metallurgist of the corporation. Both Mr. Zapffe and Mr. Bloom have the title of assistant director. GILBERT KLINGEL, formerly a technician in the production laboratory, has been promoted to administrative assistant to the director of the research division.

JAMES R. HEISING ✪ is now metallurgical research engineer at Battelle Memorial Institute, Columbus, Ohio.

W. M. BARR ✪, chemical and metallurgical engineer of the Union Pacific Railroad, has been promoted to the post of research and standards consultant for the road.

J. HASBROUCK WILSON ✪ is now affiliated with Engineering Development Associates, consulting engineers, Los Angeles.

Transferred by Kennametal Inc. of Latrobe, Pa.: BENNETT BURGE Jr. ✪, from representative at Rockford, Ill., to district manager in charge of the Detroit office.

JAY C. KING ✪, formerly heat treater for Twin City Steel Treating Co., Minneapolis, is now in charge of the heat treating department at the Naval Air Station, Seattle, Wash.

GEORGE E. RITTENHOUSE ✪, formerly connected with Peter A. Frasse Co., has been appointed sales manager for A. R. Purdy Co., Inc., New York City.

J. HUNTER NEAD ✪, formerly chief metallurgist, has been made manager of the newly consolidated metallurgical and inspection department of Inland Steel Co. R. V. MARTIN and T. S. WASHBURN ✪ will serve as assistant managers and L. S. MARSH ✪ will continue in a special metallurgical advisory and consulting capacity.

# PERSONALS

Transferred by Revere Copper and Brass, Inc.: R. C. DALZELL ⊕, from supervisor of methods, Michigan Division, Detroit, to manager of Ordnance Division, Chicago.

N. M. SALKOVER ⊕ has resigned as vice-president and general manager of the Queen City Steel Treating Co. and as vice-president of the Cincinnati Mine Machinery Co., and is now devoting his full time to Salkover Metal Processing, a company he organized in 1941.

STANLEY L. LOPATA ⊕, north New Jersey representative of the Duriron Co., has organized the Stanley L. Lopata Co., to represent the Duriron Co., the Atlas Mineral Products Co., and the Pressed Steel Co.

A. R. STARGARDTER ⊕, formerly chief metallurgist for Eastern Stainless Steel Corp., Baltimore, is now chief Metallurgist for Ajax Ele... Co., Philadelphia.

JAMES C. HARTLEY ⊕, for... chief metallurgist at Alum... Forgings, Inc., Erie, Pa., has ... appointed director of research... Heppenstall Co., Pittsburgh, Pa.

MAJOR ELTON E. STAPLES ⊕ leave from his former positio... Chicago district manager for ... Duty Electric Co., has been ... overseas on a special mission.

Transferred by E. F. Houg... & Co.: HOWARD J. FLETCHE... from sales representative in ... Chicago district to the Indiana... office.

HAROLD FISH ⊕, secretary ... treasurer, has sold out the bus... of the Ready Tool Co., Bridge... Conn., to United Tool & Die C... Hartford, and is retiring from a... business.

W. F. CHUBB ⊕, formerl... London, currently director of I... ratories at the Turkish Iron ... Steel Works, Karabuk, Turkey,... been invited to occupy the n... created Chair of Metallurgy at I... bul University, Istanbul, Turk...

JOHN HANSEN ⊕, has resi... from Simonds Saw and Steel ... Lockport, N. Y., to accept a posi... as metallurgist at the Atha W... Crucible Steel Co. of America. ... rison, N. J.

J. A. KIRKPATRICK ⊕, form... assistant to the vice-presid... National Tube Co., Gary, Ind... now vice-president and ge... manager of the Universal Fil... & Scaffolding Co., Zelienople, ...

WILLIAM ISLER ⊕ has withdr... from the firm of Fay, Golrich, ... ton and Isler and has opene... office for the practice of p... trademark and copyright la... Cleveland.

F. E. GARRIOTT ⊕, form... superintendent of the A. O. S... Corp., Houston Works Weld... Plant, is now development ma... of the Ampco-Trode Divisi... Ampco Metals, Inc., Milwaukee, ...

LT. COL. JAMES C. SKINN... until recently in charge of Air ... Officer Training in Engineeri... Communications at Yale Unive... has been assigned to duty in W... ington, D. C.

# PERSONALS

KENNETH H. J. CLARKE ⊕, formerly general executive assistant to the metals controller, Department of Munitions and Supply, and deputy administrator, non-ferrous metals (primary), Wartime Prices and Trade Board, both of Ottawa, Canada, has joined the staff of G. C. Bateman, the Canadian deputy member of the Combined Production and Resources Board, Washington, D. C., in connection with the metals and minerals activities of that board.

E. L. MILFORD ⊕, formerly with G. S. Rogers Co., has been appointed by American Gas Furnace Co. of Elizabeth, N. J., to head the Chicago office.

JOHN W. BARNET ⊕ has left the Foreign Division of WPB to be metal specialist in the Office of Economic Affairs, Department of State.

A. DI GIULIO ⊕ has opened an office as consulting chemical and metallurgical engineer in Detroit.

FREDERICK S. BLACKALL, JR. ⊕, president of Taft-Pierce Mfg. Co., Woonsocket, R. I., has been elected president of the New England Council.

G. E. WILLEY ⊕, formerly research metallurgist with Ontario Research Foundation, Toronto, is now metallurgist with N. Slater Co., Ltd., Hamilton, Ont.

ROBERT L. SWEET ⊕, formerly in the department of chemical engineering, Michigan State College, East Lansing, is now with the Chrysler Corp. in Detroit as metallurgist.

T. M. NOLAN ⊕ has been transferred to the Ordnance Division of Bell Aircraft Corp. as quality manager.

WILLIS T. CRAMER ⊕, formerly works metallurgist, American Steel and Wire Co., Cuyahoga Works, has been named assistant director of research.

J. O. ALMEN ⊕, head of mechanical engineering department 1, General Motors Research Laboratories has been awarded the Manly Memorial Medal by the Society of Automotive Engineers for his work in increasing the working strength of metals and engine parts.

EDWARD C. SLICK ⊕ has left Bethlehem Steel Co., Johnstown Plant, to become metallurgist with the Sylvania Electric Products, Inc., Bayside, L. I., N. Y.

FREDERICK G. SEFING ⊕, research metallurgist, International Nickel Co., New York, has accepted an invitation to present the official A.F.A. annual exchange paper at the 1945 meeting of the Institute of British Foundrymen.

BIRGER L. JOHNSON, JR. ⊕, formerly with General Electric Co., is now chief metallurgist in the research division of the Mack Truck Corp., Plainfield, N. J.

RICHARD J. PHILLIPS ⊕ is now director of training for Birmingham Ordnance District, Birmingham.

# DOUBLE DUTY!

## Flash Welding and Annealing in One Operation
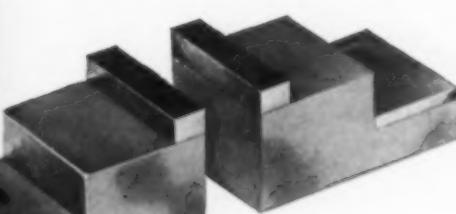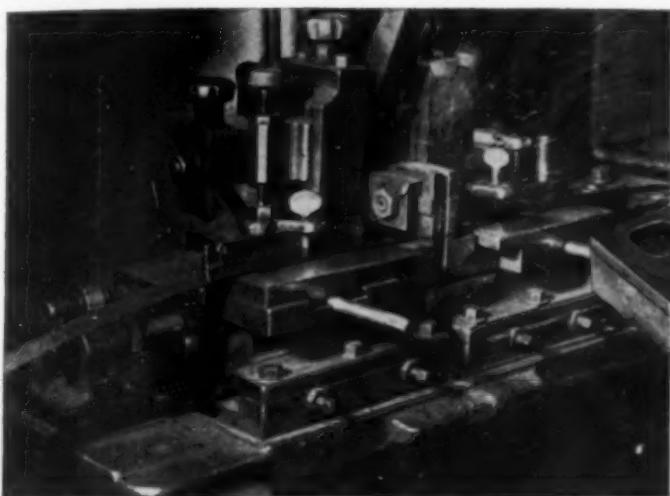


Mallory Flash Welding Dies serve a dual purpose. Band saw blades are welded and the joint is annealed in this welder.

PHOTO COURTESY E. C. ATKINS CO.

WHEN the ends of a band saw are welded to make it endless, conventional flash welding is not adequate. The high carbon steel of the welded joint cools too rapidly from its flash temperature . . . becomes brittle and unserviceable.

This problem is surprisingly easy to solve. A second pulse of current is passed through the welded joint. This reheats the weld area to annealing temperature and restores the steel's ductility.

Mallory Flash Welding Dies are used in this dual welding-annealing operation that makes band saws endless. Combining excellent electrical conductivity with hardness, toughness and wear resistance, these Mallory dies are good for many thousands of sound welds . . . with minimum down time for dressing.

Mallory metallurgists and welding engineers have developed *special electrode* materials . . . Elkaloy A*, Elkonite*, Mallory 3* Metal and other alloys for Mallory spot welding tips and holders, seam welding wheels, and dies for flash, butt and projection welding. Consult Mallory for the resistance welding electrodes you need.

Write us today if you don't have the latest Mallory electrode catalog and the new Mallory Resistance Welding Data Book. Free to users of resistance welding, when requested on company letterhead. Price to students, libraries and educational institutions: $2.50 per copy, postpaid. Board covers, 8½" x 11", 160 pages.

### P. R. MALLORY & CO., Inc., INDIANAPOLIS 6, INDIANA

*U. S. Pat. Off.*

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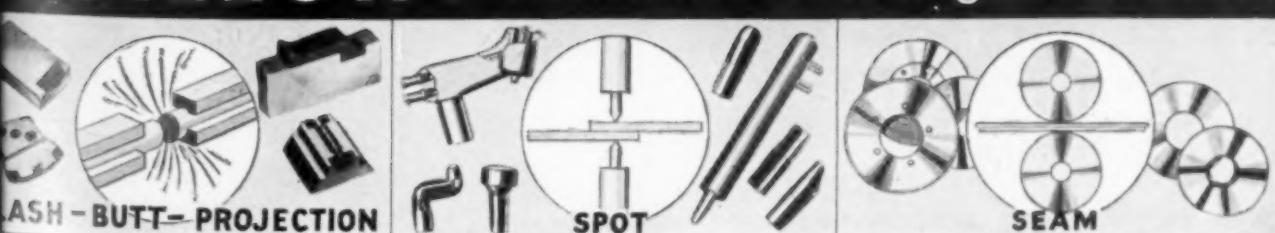
# CENTRIFUGAL STEEL CASTINGS

tion. It is considerably lower in alloying elements (and hardness), and is more coarsely columnar than the outer zone. During the later stages of tumbling equiaxed crystals form and give rise to the third or inner zone. Low mold speed, fast pouring, and high cast-ing temperature favor the formation of Type I structure.

Type III structure is characterized by highly segregated circumferential bands, essentially due to vibration of the mold and molten metal at high rotational speeds. Low casting temperature and rapid pouring are also concomitant factors of importance.

Type II structure is most desirable; with the exception of "periodicity" near the outer rim, segregated bands are absent, and hardness is much more uniform. The crystal structure, as shown by macro-etching, is generally uniform, usually having chill tals at the outside, then equi-axed crystals, then large columnar crystals, and finally equi-axed crystals up to the of the cylinder. Conditions ing Type II are freedom from tion, high casting temperature slow pouring. In it solidi proceeds normally, free from nounced chemical segregation.

The fact that the outer col crystals are normally inclined small angle to the radius cylinder is not to be explain a "drag" effect, since the tion is in the direction of of the mold. In centrifugal the liquid would normally be ing at a slower rate than the so its motion relative to the is in the reverse direction. it is known that columnar slope in the direction from a fresh supply of liquid approaches, the columnar in a centrifugal casting should toward the approaching that is, slope toward the di in which the mold is rotating.

Radial cracks were obser some of the castings, and it appear that they are associ with high mold speed and pouring. (At very low po rates, no cracks occurred the highest mold speeds and temperatures.) It seems that cracks form in the early sta solidification when the cent force of the liquid portion st the thin shell sufficiently hig crack it, after it has contra away from the mold and th its external support. Circu ential cracks occurred only pouring very slowly at low perature, conditions which lapping and cracks near the o

In summary, the most imp individual factor appears to rotational speed of the mold speeds result in "splashing" delayed pick-up, and a seg structure (Type I). Vibration be avoided. Experiments vibrated non-rotated ingots produced sharply segre streaks, so the bad effects of tion are not peculiar to the trifugal casting process, nor steel or alloy being cast. The ence of mold speed is modifi rate of pouring and casting ature. High temperature in the size of the primary and increases the solidifica time, thus favoring Type I ture. Rapid pouring does the for the same reason.